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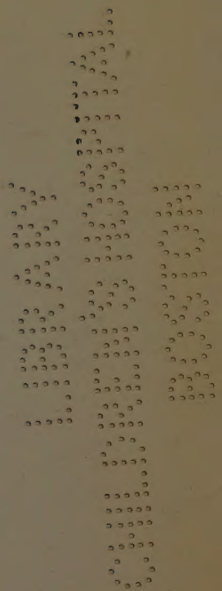

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SURGERY

ITS PRINCIPLES AND PRACTICE

BY VARIOUS AUTHORS

EDITED BY

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VOLUME VII

With 359 Illustrations, 17 of them in Colors

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PREFACE

THE first six volumes of this work recorded the progress of Surgery down to 1913. Then came the Great War and its remarkable contributions both to the Science and the Art of Surgery. Without a record of that enormous progress this work would have been a torso. Hence, immediately after the Armistice, with the approval of the publishers, I began to assemble a full staff of experts, whose work appears in Volumes VII and VIII.

One illustrious name, alas! is missing. Sir William Osler, my dear friend for thirty-five years, had acceded to my request to write the initial chapter on "The Surgeon from the Physician's Point of View." I knew that he was the only man anywhere who could plainly tell us our faults, and yet we would kiss the hand that smote us.

These volumes do not only record the achievements of surgery from 1914 to 1919. They also fulfil a second purpose I have had in view, viz.: they make available for the surgery of peace the lessons taught us during the war.

The Great War differed from all its predecessors in many ways. The armies excelled those of Xerxes and Alexander in numbers. Soon the rifle bullet was displaced to a very large extent by shells filled with high explosives and fired in almost incredible numbers. They produced ghastly and often multiple wounds which were the seat of an infection unparalleled in virulence. Lister's principles apparently went by the board. Both asepsis and antisepsis, at first, were complete failures.

It was soon found that the reason for the failure was the intensity of the infection and the appearance of one unusual source of infection—the Welch and other bacilli of gas gangrene—unknown in previous wars except by a few sporadic cases. The antiseptics in common use were unable to cope with such overwhelming infection which occurred in well-nigh every case. But experience showed that the knife, by débridement and épluchage—*i. e.*, mechanical disinfection—could master the infection by wholesale mechanical removal of the invading bacteria and of the dead and dying tissues on which they fed and flourished, provided it could be applied early enough. The few bacteria left after épluchage were easily destroyed by the restorative forces of the body. Primary or delayed primary suture after such cleansing was followed by immediate union in the vast majority of cases.

In those cases which reached the surgeon too late the chemist, the

bacteriologist, and the mathematician gave us the whip hand of the bacteria even in a very large percentage of thoroughly infected cases. We could not only obtain a cure, but even prophesy the date of complete healing.

Thus the great principle of Pasteur and Lister—that *infection is caused by bacteria* and could be conquered only by *removing or destroying the bacteria*—was established more triumphantly and more firmly than ever.

Team-work among the surgeons, assistants, nurses, bacteriologists, radiologists, chemists, neurologists, physiologists, and mathematicians accomplished undreamed-of wonders.

PASTEUR AND LISTER WERE OVERWHELMINGLY VINDICATED!

How almost complete was the victory over tetanus is shown by the fact that I had great difficulty in obtaining an author to write the chapter on Tetanus. Most of the surgeons whom I asked had seen only one or two cases, and not seldom *not a single case* of that dread disease. The only surgeons who had had a large experience in tetanus (as also in typhoid fever) were the men who entered the war in its early months. After that period the antitetanic and the antityphoid serums almost abolished both of these historic scourges of great armies.

Not only did the Germans violate the Geneva rules by repeatedly bombing hospitals and sinking hospital ships, though their character was plainly indicated by that Symbol of Mercy—the Red Cross—but, as shown by Colonel Church in his chapter on Poison Gas in Warfare, they violated their twice-pledged word at the two Hague Conferences, and had been preparing deliberately to do so long before 1914. But the Hague agreements were only "scraps of paper." "Fides Punica," that age-long reproach, has been replaced by "Fides Germanica."

Military surgeons are no longer to be classed as non-combatants. The toll of their lives and the tale of their bravery are known and read of all men. We pay a grateful homage to those of our colleagues who have been disabled, and to the memory of those who have fallen.

It is a pleasure also to join in commending the heroic bravery of the nurses, who never deserted their posts. Not a few of them lost their lives. They were indispensable to the greatest surgical success. Future wars will find them firmly established in military hospitals.

"A. E. F." (American Expeditionary Forces), "C. C. S." (Casualty Clearing Stations of the British, corresponding to the "Evacuation Hospitals" of the American Army), and one or two other contractions in the text are in such common use that every reader, I am sure, will understand them. They save space for more important matters.

For the American spelling (if I may so call it), such as center, meter (do not forget that all English-speaking peoples write thermo*meter*, baro*meter*, chrono*meter*, etc.), esophagus, hemorrhage, technic, etc., I assume the entire responsibility. I am quite aware of the shock this will give to some American readers, and especially to our British colleagues. I hope they will condone my offense, if such it be. But they ought rather to thank me for not having been far more radical, for

am I not on the Simplified Spelling Board? I am in good company, too, as is shown by the corresponding British Society. I even may claim credit for great self-restraint!

Most of the illustrations in their legends have acknowledgments of the sources from which they have been obtained. I have to record with pleasure the invariable courtesy of authors and publishers of sundry books and periodicals for permission to use certain illustrations. To General J. J. Pershing, Commander in Chief of the A. E. F., and to the Signal Corps, U. S. Army, I am especially indebted for placing at the disposal of members of the staff of Keen's Surgery their entire set of several thousand photographs. To Major-General Merritte W. Ireland, Surgeon-General, U. S. Army, of whom I am justifiably proud as a former pupil at the Jefferson Medical College, to Admiral William C. Braisted, Surgeon-General, U. S. Navy, as well as other officers in the Medical Corps of both the Services, I am especially indebted for their continued and hearty co-operation.

Not only have my readers been fortunate in having our own national surgical resources put at their disposition, but through Lieut.-General Thomas H. J. Goodwin, Director-General of the Medical Department of all the British Armies, and of Surgeon Vice-Admiral Sir William H. Norman, K. C. B., R. N., and Surgeon Rear-Admiral Sir Robert Hill, K. C. M. G., C. B., C. V. O., R. N., successive Directors General of the Medical Department of the Royal Navy, the official photographs and other resources of the British Army and Navy have also been placed freely at our disposal.

My hearty personal thanks are due to the authors, the publishers, and their employees for their cordial co-operation in the publication of these two volumes.

These two supplemental volumes complete a work covering over eighteen years, 1903–1921. The eight volumes comprise 8678 pages with 4062 illustrations, of which 154 are in colors.

The entire staff includes 129 contributors. A few—surprisingly few for so long a period of years—have passed beyond the veil.

In parting finally from these many valued friends and colleagues, still living, I gladly bear witness to their kind forbearance with my own imperfections; I thank them for their painstaking, fruitful labors, and wish for each and every one of them a happy and prosperous future.

I count it the crowning privilege of a long life to have been associated with so distinguished a company of authors.

WILLIAM WILLIAMS KEEN.

PHILADELPHIA, PA.,
February, 1921.

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SURGERY

ITS PRINCIPLES AND PRACTICE

CHAPTER I

INFLAMMATION *

By J. George Adami, F.R.C.S., F.R.S.,
Liverpool, England

While it is true that by proving all things and holding on to that which gives the best results we may, by the method of Ehrlich, with his "606," arrive eventually at *optimum* or *proximo-optimum* results, it has to be confessed that the method does not greatly appeal to the man of scientific mind. His ideal is that of the mathematician advancing inevitably from stage to stage in the solution of his problem. Doubtless the mathematician in the process of finding the right solution mentally tests and casts aside many possible methods of treating the problem, but when his result is reached each step of the proof follows an inevitable and logical sequence—no element of chance exists.

To give a concrete example, take the following problem: Given a square of sheet iron, how should this be cut up so as to form a rectangular open box having the maximum capacity? There are two perfectly valid ways of solving the problem—the first and oldest, that of multiple trying out; the second, by the employment of the differential calculus—the former indirect, time consuming, and at most, save by lucky chance, approximate; the second, direct, speedy, and precise. It is true that the second only represents the first reduced to law; true also, that a tinsmith, with no knowledge of higher mathematics but of wide experience, might, at his first attempt, construct a box with proportions which approached in a striking manner to those determined by the use of the calculus. The former is the method of the higher empiricism, the latter the method of exact science.

To a very large extent the biologic sciences are still inexact, operating by the former method. All systematic botany and zoölogy, for example, and the determination of genera and species are based not upon law, but upon empirical conventions, and, as one of the biologic

* Supplementary to Chapter V, Vol. I, p. 182, and Chapter LXXXVII, Vol. VI, p. 17.

sciences, for its advance medicine time and again has to fall back upon the method of multiple trying out.

The Great War with its unparalleled number of wounded has brought vividly before all the surgeons engaged the problem of inflammation and its treatment. Never before has the surgeon had under his eyes the reaction to injury on so vast a scale. With wounds untreated and exposed for twenty-four hours and more, that reaction has assumed forms which in civil life he has never seen, forms which he believed to belong to past ages, not to the twentieth century. He has seen pus formed and discharged literally by the pint; seen also, to his astonishment, that this discharge, if not "laudable," may continue to be poured out for days without grave injury to the patient, and, indeed, that the man with such free discharge fared far better than some neighbor in the ward in whom pus production was small in amount, but pent up.

These intensive reactions, of necessity, led each thoughtful surgeon along the front and in the hospitals along the lines of communications to endeavor to treat the wounded in the first place by methods which in civil practice had been found by him to be most successful. But one and all of these methods proved largely inefficacious, from the old-fashioned listerian antiseptics down to the immediate employment of iodin. This is not a chapter upon the treatment of inflammation, so that it is not in place here to do more than mention the many methods employed. Then, in the British Army, came the era of pastes, such as "Bipp," of hypertonic salt solutions and "salt packs" of eusol and Dakin's solution (both with a basis of hypochlorite of lime), of chloramin-T, flavin and acriflavin, of Carrel's method of flushing the wound, and of the Taylor "ebb-and-flow" method, culminating in the immediate surgical removal of damaged tissue with early suture. Steadily the treatment became more and more efficient, the results more satisfactory.

From this recital it would seem that the improved technic and improved results were the outcome of the method of multiple trying out. While this is so, it is also obvious to those who read the literature that each advance was based upon sound principles, and that all or almost all were preceded and accompanied by careful pathologic and bacteriologic experimentation. As a result the war has materially advanced our knowledge of inflammation—of the processes whereby the organism reacts to local injury, especially when this is accompanied by local infection and suppuration.

The fullest progressive study of these processes has been made by Sir Almroth Wright,* in charge of the laboratory established by the British Medical Research Committee at Boulogne, and it has in the main been published in a series of addresses delivered by him from 1915 onward to the Royal Society of Medicine in London and continued in the Lancet. His observations may, therefore, most conveniently be made the basis upon which to build our review.

* See Bibliography.

THE STUDY OF PUS AND ITS PROPERTIES

Ever since the middle of the '80's of the last century, from the days when Metchnikoff, on the one hand, published his classical studies upon phagocytosis, and on the other, Nuttall, Nissen, and others their studies upon the bactericidal action of the body fluids, workers have inclined to support one or the other school, either the cellular or the humoral. Some, like myself, have consistently attempted to bring the two together. The virtue of these more recent researches is that the two stools are brought so close together that there is no danger of falling between them; we can sit safely upon both of them. The respective parts played by the leukocytes and the plasma in the destruction of bacteria and the healing of the open wound are now seen more clearly than ever before.

A. **The Fluid Exudate.**—The observations of Opie upon the fermentative activities of pus, which were detailed in my article upon Inflammation in Volume VI, constitute the most important advance of the last twenty years in our knowledge of the means whereby the organism reacts to injury. They may truly be said to be the starting-point for the advance in the knowledge gained during the Great War. Opie, it will be remembered, discovered that whereas normal blood-serum not merely possesses no fermentative (proteolytic) properties, but actually has antifermentative powers, neutralizing the proteolytic ferments, the fluid bathing, and gained from accumulation of leukocytes, exhibits, on the contrary, definite powers of proteolysis, digesting fibrin and other proteins. When the accumulation is one of pus proper, containing polymorphonuclear leukocytes, the enzyme liberated is of one order, an alkaline medium being necessary for the process; when one of lymphocytes is of another, a faintly acid medium being necessitated.

The former enzyme, it must be noted, is not a true trypsin—the digestion is direct, not demanding the coexistence of an enterokinase.

In the ordinary infected wound the lymphocyte comes little into evidence. We may safely confine our attention to the pus corpuscle proper, the "polynuclear" leukocyte.

Pyoculture. Delbet's Method.—Delbet fills a pipet with the wound discharge; from this a spread is made on a slide in the usual manner, and a tube of peptone bouillon is seeded. The end of the pipet is then closed in the flame, and with the tube of inoculated bouillon the pipet is placed in an incubator, preferably in a moist chamber. At the end of twenty-four hours a film is made from the bouillon and also another from the pus in the pipet; all are appropriately stained. A study of the preparations enables him to arrive at the following conclusions: (1) A "*pyoculture positive*" (abundant growth in pus, more abundant than in the bouillon) indicates a very grave prognosis and demands large débridements. (2) A "*pyoculture nulle*" (no growth in the pus, growth in the bouillon) indicates that the patient's response to infection is unsatisfactory and that therapeutic aid should be given. (3) A "*pyoculture negative*" (bacteriolysis of the microbes in the pus) indicates the triumph of the patient and demands abstention.

As many wounds are polymicrobic the pyoculture may be positive for the streptococcus and negative for the staphylococcus, positive for the streptococcus, negative for B. welchii. The continued growth of infecting organisms in the wound discharge is ominous, indicating an insufficiency or absence of inhibiting and antagonistic substances. In most instances the pyoculture is in accord with the opsonic index, and usually when not so the clinical evolution follows the course indicated by the pyoculture.

Trémolières and Loew have verified the observations of Delbet and extended their studies to the relation of pyoculture to opsonic index.

Here, then, a simple method is afforded of obtaining an *apparently* trustworthy forecast of the future of the wound. If the microbes definitely fail to grow in the pus this is clear evidence that the patient is providing a good immunizing reaction and that, given proper attention, the wound is likely to progress favorably to full healing. If, on the other hand, the bacteria undergo multiplication the interpretation is not so simple (hence our employment of the limitation "apparently"). While, on the one hand, it may mean that there is a lack of immunizing or bactericidal response on the part of the patient, the explanation may be that old and not fresh pus has been selected, that a sample has been taken from an area of the wound in which the pus-cells have broken down, liberated their proteolytic ferment, and given rise to dissociation products which form a good food on which the bacteria thrive.

It deserves note that A. Policard, in what is perhaps the soundest and most thorough individual study of the bacteria of war wounds, arrives at a similar conclusion; while admitting that Delbet's method affords highly suggestive indications, he doubts if the prudent surgeon can lean too heavily on the findings of this method, and, indeed, warns against giving undue weight to those findings.

Pyoseroculture. Wright's Method.—Sir Almroth Wright has improved upon this by his method of pyoseroculture (1915). A few years before the war Abderhalden had shown that if a foreign protein be injected into the tissues then, within twenty-four hours, the blood gains the power of splitting up and peptonizing not only the particular protein inoculated, but other proteins. In other words, as a first stage in the process of immunization against any specific protein (bacterial bodies, it may be noted are largely protein), there is the rapid development or exaltation of the property of non-specific dissociation, or peptonization, of proteins in general. Wright calls attention to the fact that an important factor in the healing of suppurating wounds is a parallel progressive increase in what he and others term the "antitryptic" power of the patient's serum. There is, he shows, a striking increase in the power of the serum of the circulating blood of the patient to inhibit the growth of bacteria.

Normal blood-serum has a definite inhibitory action upon most of the bacteria which gain entrance into wounds, and, indeed, upon the great majority of pathogenetic bacteria. This is the explanation why

in the old days, before special methods were employed, it was so repeatedly found that in diseases such as typhoid the blood was sterile. Before special methods of dilution and trypsinization of blood were developed the only microbes which could commonly be gained by culture from the circulating blood were streptococci and to a less extent streptococci. With this in mind Wright—1915 (2)—classifies wound bacteria into three orders: (1) *Serophytes*, (2) imperfect or *secondary serophytes*, and (3) *serosaprophytes*. Streptococci and Staphylococcus pyogenes come into the first class; they grow freely in normal serum. The majority of wound bacteria belong to the third class; not growing in wound serum, but proliferating freely in serum or lymph which has been "corrupted," *i. e.*, which contains dead and broken-down leukocytes and their products. To the category of imperfect serophytes belong Welch's bacillus (B. perfringens), B. proteus, B. pyocyaneus, and a wisp-like diphtheroid bacillus frequently found in foul suppurating wounds; these produce no growths in serum when a few only are added, although they multiply when a heavy implantation is made, presumably because all give off strong proteolytic enzymes.

Within thirty-six hours or less after the infection of a wound the "antitryptic" index of the circulating blood-serum has risen far above the level of the normal. Reckoning the "antitryptic" power of normal serum as unity, indices of 4 and 5 were found very common in patients under treatment at the base. Like Abderhalden's reaction above noted, Wright points out that this is a non-specific phenomenon. He found a similar, if smaller, increase in the blood-serum after inoculating himself and his colleagues, the one with typhoid vaccine (dead typhoid bacilli), the other with streptococcus vaccine, and a third with staphylococcus vaccine.*

This, in the first place, stands out, that old pus becomes the prolific breeding ground for bacteria. Just as years ago Sir William Roberts

* For myself I object to this being termed an "antitryptic" phenomenon. Wright and others, it seems to me, have confused enzyme production and the results of enzyme action. The blood-serum in the wounded man, I suggest, does not become increasingly antitryptic, but gains a progressive increase, in the first place, of non-specific proteolytic enzyme (Abderhalden reaction). It is this increase that in the first place arrests bacterial growth. But if such serum or lymph is given time to act, and the products of proteolysis are not given opportunity to diffuse away and be resorbed, and if this proteolytic enzyme is, in addition, reinforced by proteolytic enzymes derived from the broken-down leukocytes, eventually the pent-up pus becomes peculiarly rich in just those bodies which form *par excellence* the food-stuffs suited to wound bacteria, and now the bacteria, in place of being inhibited, undergo multiplication. It is not, as Wright explains it, a case of trypsin and antitrypsin, but of alteration of the equation between favorable and unfavorable growth conditions. What Wright regards as a demonstration of the existence of antitryptic bodies, namely, that the addition of trypsin to a definitely antibacterial serum converts that from an unfavorable to a favorable medium of growth, may be more simply explained by the action of the added trypsin in breaking down the proteins present and setting free tryptophane and other bacterial food-stuffs. As an adjuvant it may be added that trypsin more readily attacks inert protein material than it does the living bacteria.

Here it may be added that along these lines we gain some understanding of Wright's latest observations (March, 1919) upon the increase or decrease in the bactericidal power of blood-serum *in vitro* according to the amount of vaccine (suspensions of dead microbes) added to that serum.

pointed out that the fresh oyster is a most excellent food for delicate invalids, in that its peptic and other enzymes lead it to digest itself and so save the invalid the trouble, so the pus-cell when it dies digests itself (undergoes autolysis), and doing this liberates into the surrounding fluid the soluble dissociation products of its proteins, and these, as already stated, are the main food-stuffs of wound bacteria. Thus while the fresh wound exudate, formed of living leukocytes bathed in lymph (that is to say serum), permits only the serophytes to grow, the old

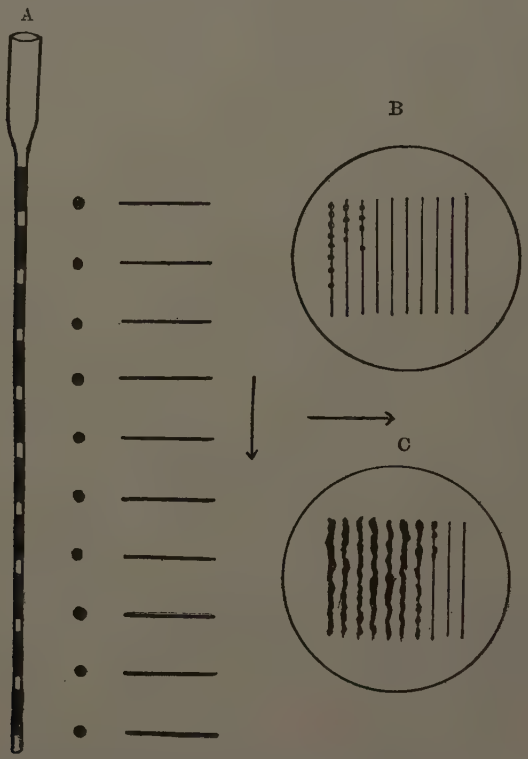

FIG. 1.—A, Pipet which has been implanted by Wright's "wet-wall" and "wash and after-wash" procedure with successive dilutions of pus in serum *(vide* text). By the side of the pipet to the right the large black dots represent the successive units of the pus-serum suspensions which have been blown out upon a sterile slide after incubation. To the right of the dots the series of lines represent the linear implantations made from the dots (or unit volumes) upon agar. B, Diagrammatic representation of a Petri dish of agar implanted from successive dilutions of pus in unit volumes of *the patient's* blood-serum. C, Similar linear implantations from successive dilutions of the same pus in unit volumes of *normal human* blood-serum used as a control. (Sir A. E. Wright.)

exudate, rich in dissociation products, forms a rich medium for serophytes and serosaprophytes alike, and herein lies the weakness of Delbet's method; his results are conditioned by the age of the pus.

This difficulty Wright surmounts. Taking two equal samples of the pus from a wound, he makes with each a parallel series of successive dilutions, and of these dilutions (Fig. 1, A) in the one series he mixes equal quantities with drops of the patient's blood, in the other series the blood-serum of a normal individual. Now, drawing these drops

of either serum into its respective capillary pipet* in such a way as to avoid contamination of the lighter implanted with the heavier implanted drop, each drop being separated from its neighbor by a bubble of air, he closes the distal end of the pipet and incubates it at 37° C. for from six to twenty-four hours. The incubated drops are then expelled from the pipet on to a clean slide. With a platinum wire he then makes a series of parallel streaks—one for each successive drop of implanted serum—upon the surface of an agar-plate and incubates the two plates to observe the richness in colonies of the successive streaks. Figure 1, B and C shows the results gained in an actual experiment.

"In cultures made with the serum of a wounded man who is making a satisfactory immunizing response . . . we have in both series of sero-pyocultures only serophytes—staphylococci and streptococci—but while the cultures made with the patient's serum furnish only a few discrete colonies, and these only in the first (dilution) and the two succeeding, we have with the normal serum (C) in the first seven plantings massed colonies, and in the eighth discrete colonies."

In this way, repeating these observations upon successive days, it is possible to determine the progress of the wound as well as the part played by the body fluid in arresting bacterial growth and bringing about an arrest of the local infection.

The "Lymph Leech."—That the lymph—the fluid exudate—of the wound has the same properties in this respect as has the blood-serum has been demonstrated by Wright by the employment of his "lymph leech," a convenient form of cupping glass—a small test-tube with its open end drawn into a nozzle and provided with a lateral mouth (Fig. 2). To the nozzle is fitted a fairly thick piece of rubber tubing,

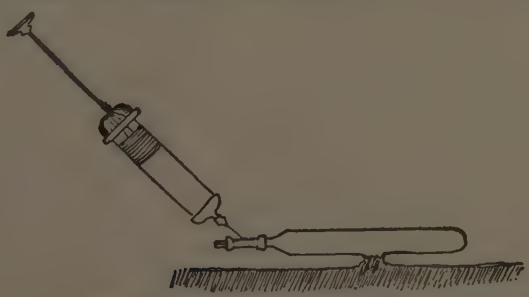

FIG. 2.—LYMPH LEECH. (Sir A. E. Wright.)

blocked at the free end by a piece of glass rod. The lateral opening of the leech is brought down upon a cleansed area of a granulating wound, and then, transfixing the rubber with the needle of a hypodermic syringe, air is drawn out and a negative pressure induced. This now holds on tight to the wound between dressing and dressing, and furnishes an exudate free from contamination with the residual pus of the wound. It can be employed for various experiments, influence of particular antiseptics, etc.

* For full details of Wright's technic consult his lecture to the Royal Society of Medicine, October 8, 1915.

The prime observation is that, whereas the surrounding opaque pus may be swarming with all manner of microbes, the fluid within the leech is clear or slightly blood-stained, containing streptococci (serophytes) in practically pure culture, with, in addition, a few leukocytes which are actively phagocytic. We have the same results as when we make an implantation of pus into serum.

From these demonstrations certain valuable conclusions may be drawn and principles—or laws—established:

1. The fresh lymph exuding into a wound exerts a powerful influence in preventing the growth of most forms of bacteria which gain entrance into a wound.

2. In those presenting the usual powers of systemic reaction this antibacterial or inhibitory power of the fluid exudate undergoes a rapid increase.

3. The different species of wound bacteria are not influenced to the same degree; the microbes least influenced by these properties of the lymph are the streptococci as a group and Staphylococcus pyogenes.

4. The lymph is able to exert these powers so long as it is fresh; if pent up and not allowed free drainage, then, with the progressive breaking down of the contained leukocytes and other cells, and liberation of their dissociation products, from being an unfavorable it becomes a most favorable medium for the growth of all orders of wound bacteria.

5. *When a wound is infected it is all important to prevent the accumulation, with stasis, of the exudate.*

6. A badly infected wound can be cleansed of most forms of bacteria by the action of the lymph of the exudate alone, provided that this be allowed free drainage.

7. In certain wounds—*i. e.*, in freely exposed or open wounds without pockets, in which lymph and pus can stagnate—it will be of positive advantage to increase the flow of the exudate, as by means of Wright's hypertonic salt solution (5 per cent. NaCl solution).

B. **The Pus-cell.**—So much for these war-time demonstrations of the part played by this fluid of inflammatory exudate. Next as to that played by the leukocytes.

It is true that, as Wright points out, Metchnikoff, in the extraordinarily brilliant series of observations whereby in the '80's and '90's he established the importance of phagocytosis, relied (almost wholly) upon experiments *in vivo*. Certain of his followers (Massart and Bordet, Gabritchewski, and Buchner) introduced a combination of the *in vivo* and *in vitro* methods by observing the effects of introducing into the body cavity capillary tubes closed at one end and containing substances of various orders—young and old cultures of bacteria, the filtered products of growth of the serum, and solutions of various salts. They found that certain substances exercised a strong attraction, others none at all, no leukocytes entering the tubes. The most striking demonstrations of these chemiotactic properties are the following, which we owe to Leber:

Through a fine nick in the wall of the jugular vein of animals of the laboratory introduce into the flowing blood fine capillary tubes drawn into a hook shape, so as to catch on to the incision and remain *in situ*, the hooked end being closed. These tubes may be filled with bacterial suspensions of various orders, with mercury and other chemicals. According to the nature of their contents and the concentration of the serum it is found that leukocytes are attracted out of the flowing blood into the tubes. Sometimes the attraction is so active that a dense plug of polynuclear leukocytes fills the lumen of the tube. It is an absolute demonstration of the chemiotactic properties of certain substances.

Wright's pupil and successor at the British Army Medical College, now Sir William Leishman, gave us the simple method of demonstrating *in vitro* the phagocytic properties of the human leukocyte, viz.: Clean the finger, take a drop from it; mix with an equal quantity of a suspension of any pathogenetic microbe; drop the mixture on to a slide; place upon it a cover-slip; set the preparation in an incubator at blood heat for fifteen minutes; then rapidly remove the cover-slip, fix the pus, and stain by any good bacillary stain. The polynuclear leukocytes are seen to have taken up in this short time abundant bacteria. It is shown by this method that there is no pathogenetic microbe which, under favorable circumstances, the polynuclear leukocyte cannot ingest. Now with characteristic ingenuity Wright himself has devised a method, also *in vitro*, for studying under various conditions the chemiotactic and phagocytic powers of the leukocytes. He utilizes the framework created by the fibrin of the blood-clot to retain the cells in position and estimate the extent of their wanderings and their phagocytic activities.

"The principle of this method is as follows: We fill in a capillary tube with blood from a prick in the finger, immediately placing the capillary tube in a centrifuge, and centrifugalize until we have carried down all the corpuscles. We have now in the upper part of the tube a plasma which has been completely freed from all formed elements; and in the lower half of the tube, at the bottom, the red blood-corpuscles intermixed with a certain number of polynuclear white blood-corpuscles; and above this a layer made up predominantly of white blood-corpuscles—these last in the front ranks consisting almost exclusively of small and large mononuclears. The blood now clots, and this gives in the upper half of the tube a clot (let us call this the *white clot*) consisting of fibrin without any formed elements, and in the lower half of the tube a clot (let us call this the *red clot*) which holds all the corpuscles in its meshes. When a chemotactic stimulus now comes into application from above the white corpuscles will come out from the red clot, and will travel upward through the meshes of the white clot, afterward maintaining their position so as to allow of our making measurements and enumerations."*

For purposes of easier examination under the microscope Wright employs flattened capillary tubes, easily made and drawn out in the

* Wright, 1915, p. 14 et seq.

laboratory. These can be examined immersed in fluid under a cover-glass; or the clot may be blown out into water, washed free from loose surface cells, and then fixed on a slide, stained, and mounted. Figure 3 indicates the order of appearance which may be gained by this

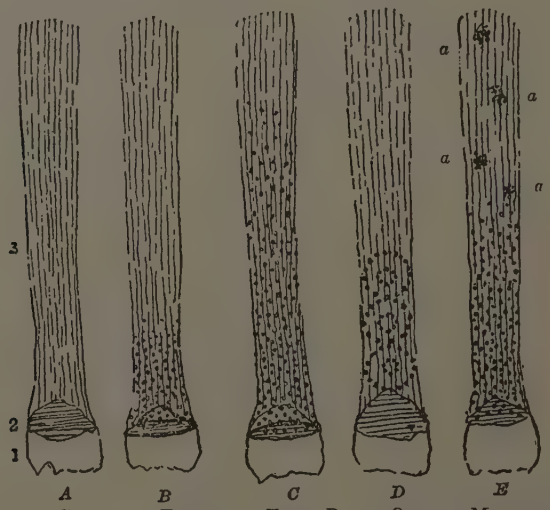

FIG. 3.—CLOTS FROM EMIGRATION TUBES BLOWN OUT AND MOUNTED.

A, No emigration; *B*, compact emigration; *C*, dispersed emigration; *D*, method of dividing up the clot for purposes of enumeration; *E*, bacterial colonies (*a*) coming up only in portion of clot which has not been reached by the emigrating leukocytes. (Sir A. E. Wright.)

method. Bacteria in suspension may be introduced above the blood before centrifugalization, and the microbes, being heavier than the fluid blood, will sink and disperse themselves through the upper half of the column. Salts in solution—to test their chemiotactic influence—can be added either before or after centrifugalization.

By this method we note the following facts:

1. Leukocytes emigrate more actively at 40° C. (fever heat) than at 37° C. (blood heat); emigration is arrested at 10° and 15° C.

2. Anaërobic conditions are more favorable to emigration than are aërobic.

3. Both mononuclears and polynuclears may emigrate, although under certain stimuli there may be a differential migration of polynuclears alone. In all cases where there is positive chemiotaxis the polynuclear leukocytes exhibit greater activity and, passing the mononuclear, occupy the more distal portion of the field.

4. Bacterial suspensions vary in their action according to the species employed and according to their concentration. Concentrated suspensions in general suppress emigration, whereas the same suspensions when diluted 10 to 100 times are positively chemiotactic.

5. The chemiotactic effect varies also according to the individual. Wright finds, as did Metchnikoff, that inoculation is followed by greater sensibility on the part of the leukocytes and a more pronounced positive chemiotaxis.

6. In general when, by superposing and centrifuging, a heavy sowing of microbes has been implanted into the unclotted blood, migration of leukocytes into the white clot is completely checked, and bacterial colonies show themselves throughout it. When there has been a relatively moderate implantation the results differ in the different areas of the white clot. In the intermediate zone—that is, in the region where the microbes can grow before the leukocytes arrive—one notes with the microscope areas of accumulation of leukocytes. These are young colonies which are being broken up and dispersed by the invading leukocytes (Fig. 4). With the oil immersion it can be seen that every leukocyte in such an area has taken up and is packed with the microbes which, as indicated by their appearance and staining, are in various stages of digestion (Fig. 5). At the base of the white clot, which had been earliest invaded by the polynuclears and where they had been present in largest numbers, there is an entire absence of microbic growth.

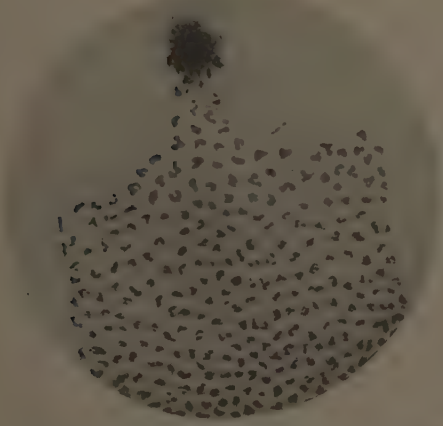

FIG. 4.—EXTREME LIMIT OF EMIGRATION, SHOWING PHAGOCYTES ATTACKING STREPTOCOCCUS COLONY. (Sir. A. E. Wright.)

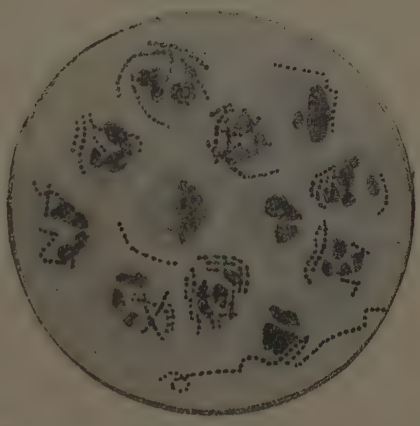

FIG. 5.—PHAGOCYTOSIS OF STREPTOCOCCI TOWARD EXTREME LIMIT OF EMIGRATION. (Sir A. E. Wright.)

The conflict (at 37° C.) is generally in its most interesting phase in from three to six hours; later either the microbes or the leukocytes are the masters of the field.

Wright, Fleming, and Colebrook have carried further these studies of the bactericidal powers of the leukocytes in their paper published in The Lancet of June 15, 1918. As has already been pointed out certain species of bacteria ("serophytes") grow freely in the blood-serum and the lymph of the inflammatory exudate. They are not wholly insensible to the influence of the serum; there are other media in which they grow more actively, and it deserves note that as through inoculation the blood-serum increases in antibacterial powers the growths become more and more scanty. But still some persist. In other words,

by increasing the exudation of the fluid into a wound we cannot wholly destroy the infecting streptococci and staphylococci.* On the other hand, as just shown, under favorable conditions the polynuclears actively ingest and destroy these microbes. Why, then, do they persist in suppurating wounds?

Evidently this depends upon the relative abundance of *fresh* polynuclears and of serum (or lymph) respectively.

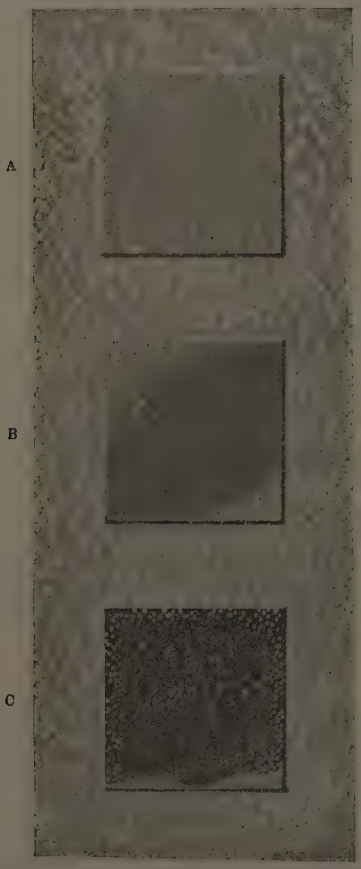

FIG. 6.—EFFECT OF IMPOSING SAMPLES TAKEN FROM CENTRIFUGED BLOOD UPON AN AGAR SURFACE THICKLY IMPLANTED WITH STAPHYLOCOCCUS.
A, Sample of serum. B, Sample of leukocytic layer. C, Sample of red blood-corpuscle layer. (Sir A. E. Wright.)

Take first a small test-tube of fresh defibrinated blood and centrifugalize. Next have ready an agar-plate which has just been sown with a fairly heavy suspension of streptococci or staphylococci. Now drop on to this plate (*A*) a drop of the clear serum from the upper layer of the centrifugalized blood, (*B*) a drop from the white corpuscle layer, and (*C*) one from the lower red corpuscle layer. Cover each drop with a cover-slip and incubate for twenty-four hours.

The results are shown in Fig. 6. In the serum drop (*A*) there are just as many colonies as upon the surrounding agar, although they are smaller. Under the cover-slip (*B*) from the white corpuscle layer practically no colonies make their appearance. The red corpuscle layer (*C*) yields abundant colonies.

If from a clean wound with "uncorrupted" exudate—a wound yielding only serophytic bacteria—we take a drop of thick pus, place this on an agar-plate, cover with a cover-glass, and incubate, we reproduce largely the conditions seen in (*B*) drop from the white corpuscle layer of the preceding experiment. The central area where the leukocytes are closely apposed remains sterile; only round the edges, beyond the leukocytes, where a rim of fluid has been expressed, do a certain number of colonies of streptococci show themselves.

If simultaneously we mix a drop of fresh blood-serum with another drop of the same pus, and treat this in the same way for comparison,

* For further studies of the increased bactericidal powers of the blood-serum over serophytes see the paper by Wright and Colebrook, Lancet, March 29, 1919.

we find that wherever the streptococci have been washed out of the pus we get colonies developing (Fig. 7, A and B).

Or compare four-hour-old pus (*i. e.*, pus from a wound carefully washed out with physiologic salt solution four hours previously) with twenty-four-hour-old pus. In the former the pus sterilizes itself by

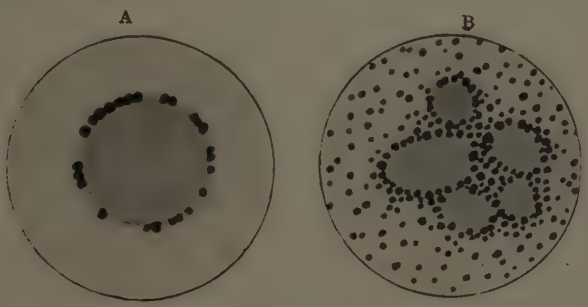

FIG. 7.—A, Pus from a clean wound spread out on a sterile agar surface under a cover-glass and incubated. Streptococcus colonies develop only in the narrow ring of serum beyond the edge of the pus. B, The same pus stirred up with serum, but in other respects treated in exactly the same way. Streptococcus colonies develop in the serum everywhere round the pus. (Wright, Fleming, and Colebrook.)

phagocytosis; in the latter, although it has still strong bactericidal powers, nevertheless a certain number of colonies develop in and around it.

THE EXISTENCE OF NEGATIVE CHEMIOTAXIS

Pfeffer, Stahl, and other botanists, studying the simpler and motile forms of plant life, first established the existence of "chemiotropism," *i. e.*, the movement of motile living matter in relationship to foodstuffs and substances in solution. With forms like the *Myxomycetes* it is easy to show that this may be of one or the other order; there may be a positive chemiotropism (or chemiotaxis) when the influence exerted makes the organism move *toward* the reagent, as also there may be the reverse movement *away* from the reagent, exerted by reagents of other orders or reagents of the same order in greater concentration—a *negative chemiotaxis*. Gabritchewski, and later Metchnikoff, finding abundant evidence of the existence of the former condition on the part of the leukocytes, postulated the existence of the latter also. Kanthack in the '90's called attention to the absence of any definite proof that leukocytes exhibit negative chemiotaxis. Leukocytes, it is true, might not be attracted to move toward certain areas of greater concentration of soluble substances, but non-attraction is not negative chemiotaxis—is not the demonstration of an active repulsion. For many years I have sought for evidence of actual negative chemiotaxis on the part of leukocytes. By homology it ought to exist. Wright has brought forward—1915 (2)—the needed demonstration. If blood be drawn into a flattened glass chamber and centrifugalized forthwith and then be allowed to coagulate, with the resultant production of the thin leukocyte layer lying between the white and red clot, he shows that if now a 5 per cent. NaCl solution be superposed, with diffusion of salt through the

white clot, not merely is there no attraction of the leukocytes upward, but, on the contrary, there is a definite wandering on their part into the red clot, away from the salt (Fig. 8, A).

That this is a negative chemiotaxis proper is confirmed by repeating the experiment, employing, however, a dilute (0.85 per cent.) NaCl solution in place of the more concentrated. With this strength there is very evident positive chemiotaxis with no more leukocytes in the red clot than under ordinary conditions (*i. e.*, without addition of salt solution—Fig. 8, B).

FIG. 8.—WE HAVE REPRESENTED IN A AND B THE LOWER PORTION OF THE WHITE AND THE UPPER PORTION OF THE RED CLOT OBTAINED BY CENTRIFUGING BLOOD IN ONE OF EMERY'S CELLS.

The white corpuscles only are shown in the figure. In A, strong salt solution has been imposed upon the free surface of the white clot. In B, physiologic salt solution has been imposed. The appearances are described in the text. (Sir A. E. Wright.)

By the use of strong hypertonic salt solution, as Wright points out, we may wholly suppress the migration of leukocytes into a wound; though whether this is an advisable procedure is debatable, since in their absence the serophytic streptococci are apt to multiply. The hypertonic solution may be of temporary use in clearing the wound, but following this the migration of leukocytes should be encouraged so that they may suppress the streptococci through their phagocytic activities. As the simplest medium to stimulate this migration he recommends the employment of physiologic salt solution.

THE DEAD TISSUE

There is no question that dead tissue and "slough" in a wound forms a highly favorable nidus for the multiplication of bacteria, and particularly for anaërobic bacteria. Many years before the war it was shown that making no special endeavors to secure absence of free oxygen from the medium of growth, strict anaërobes, such as Welch's bacillus, can be induced to multiply freely. One has only to drop a piece of tissue from a freshly killed animal—a piece of kidney or liver, for example—into a tube of peptone beef broth, preferably containing 1 per cent. glucose, and then, without taking any further precautions, inoculate the open tube with anaërobic bacilli, or their spores, and an active growth results in and around the dead tissue.* As a matter of

* As possibly a natural outcome of his strong individuality Wright is apt to be a little careless in his reference to the work of others. He ascribes this observation to Tarozzi. In America we have usually given the credit to Theobald Smith, who recorded it not ten but twenty years ago and more. (See Bibliography.) Ori and Wrszosek find that vegetable matter—*e. g.*, a piece of potato—serves equally well.

fact, no anaërobe has so far been isolated which by this method cannot be made to grow in open tubes exposed to the air.

This does not mean that anaërobic bacteria are not anaërobes and that their growth is not arrested by the presence of free oxygen. Take any of the growths of such microbes made upon meat or potato tubes, and secondary cultures will fail to materialize if made upon open tubes of glucose bouillon to which no meat or potato is added. Again, as Wright shows, if the bulk of the fluid be removed from a potato tube and if the test-tube be slanted so that the potato is in part exposed to the air, at most a meager growth results. The same arrest of growth is brought about when air is bubbled through the culture.

Alexander Fleming, Wright's colleague at St. Mary's Hospital, London, has devised experiments which afford explanation of this paradoxic phenomenon. He found that he could obtain like results if in place of meat or potato he placed asbestos wool or a pledget of cotton-wool in a glucose bouillon tube; or platinum black, or a rust-covered nail, or, most instructive of all, if he introduced into an open bouillon tube a hair-fine capillary glass tube filled with a minute quantity of a diluted culture of Welch's bacillus. What is common to these various cases must certainly be the mechanical factor "of some hole or cranny to serve as a nidus in which the microbe can get a start by concentrating its chemical effect upon a fractional portion of the provided culture-medium." In the body the blood-serum and the lymph of the exudate have a pronounced antibacterial effect upon wound anaërobes; the bacteria are protected against the mass effect of the exudate, one may say, by hiding in crevices and what may be termed capillary channels within the dead tissues. While proliferating thus in security the products elaborated by them are concentrated, and exert in their turn a mass effect, neutralizing or destroying the "antibacterial" properties of the lymph in their immediate neighborhood. They prepare thus a widening zone favorable to the growth of the anaërobes.

The dead tissue in the wound affords another favoring factor: the tissue in dying, from being alkaline, becomes acid in reaction, and a moderate grade of acidity promotes the growth of forms like Welch's bacillus, while at the same time it arrests the "antitryptic" action of the lymph.

Yet another external factor comes into play favoring the proliferation of anaërobes, namely, the admixture of aërobic along with anaërobic bacteria in a wound. Under ordinary conditions B. tetani, or its spores, introduced alone into the tissues, fail to grow and set up any disturbance. It requires also a larger dose of B. perfringens to gain a foothold and grow. Here certain reservations need to be made: if the tissue at the region of injection is dead and acid, growth is apt to ensue; as it is also when the alkalinity of the tissue is reduced by the simultaneous inoculation of lactic or other weak acid. But when there is free access of unaltered and antitryptic lymph, growth is arrested unless there be simultaneous inoculation of aërobic microbes, staphylococci, B. coli, and the like. These are indications that particular

species of aërobes aid the growth of the anaërobes. Recent observations made by members of the British Tetanus Committee indicate that tetanus bacilli are to be isolated from a large proportion of cases of shell wounds—a very much larger proportion than eventually succumb to tetanus. These observations suggest that in many wounds the conditions of symbiosis are not such as promote the growth of the tetanus bacilli.

More studies are needed upon this subject. The important point is that, contrary to the older teaching, it is obvious that the slitting open of the affected areas in cases of gas gangrene, by means of multiple free incisions, is not of service as exposing the anaërobic gas bacilli to free oxygen and thereby arresting their growth. The good effect obtained by this procedure is evidently brought about by the free drainage set up, by the removal of the old "corrupted" lymph, and flushing of the area with fresh antibacterial exudate.

Much has been learned during the war regarding the organisms setting up gas gangrene, and regarding the tetanus bacilli and other anaërobes. These matters, however, belong to a chapter upon "wound infection" rather than upon inflammation.

THE SUCCESSION OF BACTERIA IN WOUNDS

Here, at most, it may be serviceable to impress upon the surgeon that he must be prepared to find that the bacteriology of a given wound is not constant. If one studies the process of maturation of a dung heap—or of a Camembert cheese (forgive the juxtaposition!)—one finds that there is an orderly succession of species of bacteria which succeed each other. One form or group of forms finds conditions favorable to growth, multiplies exceedingly until the time comes when through the presence of the products of its activity it "stews in its own juice" and dies out, to be succeeded by another group of forms, and this, in turn, by another.

The same is true in open wounds. Tissier has made cultures from a long series of war wounds and records the following: He distinguishes between two orders of wounds, the simple suppurative and the putrefactive, the former of slow, the latter of rapid, evolution. (Those containing tetanus bacilli he places as a class apart.) The former contain mainly cutaneous organisms along with staphylococci and streptococci; the latter (putrefactive) must have a prepared ground of dead tissue.

In the ordinary circumscribed putrid wound for six or eight hours after infliction the blood fluid escaping is almost aseptic; only about the tenth hour do we find that microbes are beginning to multiply; in from twelve to twenty-four hours their number becomes considerable. At first cocci predominate, notably the enterococcus of French writers (Streptococcus fæcalis). On the second day, however, B. perfringens (Welch's bacillus) dominates the scene; with it are colonies of other anaërobes, such as B. bifermentans, B. putrificus, and "Vibrion septique" (B. œdematis maligni). In the course of the third day the proliferation of the anaërobes lessens; by the fourth day the arrest in their growth is

most marked, and now the aërobes once more are equal in number to the anaërobes, and from now on there is a gradual reduction in all forms present, the numbers reaching a minimum toward the tenth day. From now onward a new group of bacteria takes the field, forms such as B. pyocyaneus and B. fluorescens. This in a "treated" wound, but if bits of cloth and other foreign bodies remain in the wound the putrefying process continues round the foreign substances and, more particularly, B. putrificus and the "Vibrion septique" remain.

This antagonism between wound bacteria has been strikingly exemplified by Donaldson in his studies upon the "Reading bacillus." This is a strongly proteolytic anaërobic bacillus isolated from wounds at the Military Hospital, Reading, England. Not only is this found to attack and dissolve dead tissue, but it splits up the toxic products of other bacteria, thus bringing about the healing of the wound from the bottom. Donaldson himself and others have, with good results, introduced cultures of this anaërobe into wounds. *Per se* it produces no harmful substances, and does not spread into the tissues, so that its introduction into a wound is accompanied by no ill effects save foul odor.

Where the suppuration shows a tendency to extend steadily Tissier found the true pyogenic organisms in the ascendency (Staphylococcus albus and aureus); where the extension is rapid, Streptococcus pyogenes is usually responsible.

A fuller study is necessary of this matter. It is clear in the first place that either the fecal and cutaneous flora of the British soldier varies from that of the French, or that the soil flora of the different areas along the front varied within wide limits, or both. These observations of Tissier do not wholly tally with those of the bacteriologists of the British Army; the latter, however, noted wide differences between the bacteriology of the richly manured Flanders and Marne districts and the less cultivated areas around the Somme.

THE EFFECT OF FOREIGN BODIES IN WOUNDS

It is not generally realized how frequent foreign bodies are in the wounds made by projectiles. We are apt to look for bodies visible to the naked eye and base our estimate upon these, but if, following the example of my old colleague, Major (Professor) L. J. Rhea of No. 3 (McGill) Canadian General Hospital,* *a careful microscopic study be made of the exudate secured from the track of projectiles it is remarkable what a large proportion of these exudates afford threads of khaki and other tissues*, and these threads, like the rusty nail of Fleming's experiment, form foci for the multiplication of anaërobic bacteria. They indeed, rather than discrete particles of the actual soil of the battlefield, form the means whereby the infecting agents are conveyed into the wound, and so long as they remain in the wound they form what Wright some years ago termed "niduses of lowered bacteriotropic pressure," *i. e.*, regions in which, collected together, bacteria by active and passive

* Personal communication.

chemical force can maintain conditions propitious to their survival, areas in which they are protected from the action of the leukocytes.

But *among these foreign bodies the most sinister* (as maintaining for weeks and months and even years foci of bacterial growth and activity) *are fragments of fractured bone*, as also necrosed areas still remaining in continuity with the living bone. Primarily these are aseptic, but however far they may have been driven into the tissues away from the main track of the projectile, the secondary tracks of the passage of the separated fragments are apt to be continuous with the main wound and the fragments become surrounded by an infected exudate. Examination of such necrosed bone reveals that the haversian canals become filled with bacteria which have grown inward from the surface. The dead bone comes to constitute a framework protecting the bacteria securely from the action of the leukocytes, while their concentrated products of growth neutralize the inhibitory powers of the fluid of the inflammatory exudate.

A study of the exquisite series of bone specimens made by Major Rhea at No. 3 (McGill) Canadian General Hospital at Boulogne could not but impress the surgeon with the fact that while a mild degree of infection and suppuration acts as a stimulus to new bone formation, and while if portions of bone still retaining their vascular connection be left in the wound these become the centers for remarkable new osseous development, so that through the retention of fragments large gaps may be bridged over, *nevertheless among a dozen, it may be, of live fragments there are almost sure to be one or more that are dead*—cut off from their blood-supply. And these dead pieces *remain constant sources of irritation:* so long as they are present they are foci for suppuration and sinus formation. Thus clearly, following the teaching of certain French surgeons, it is the more rational surgery to remove all fragments of broken bone, and trust to osteoplastic operations at a later date when, with the wound healed, the danger of suppuration is reduced to a minimum. Yet here a caution must be given.

LATENT INFECTION OF THE HEALED WOUND

Before the war isolated observations had from time to time been published upon latent infection, and the retention in healed tissues of still living bacteria, capable under altered conditions of taking on active multiplication and of starting a renewed infection after months and, it might be, years of quiescence and apparent complete cure of the particular disease. The most familiar examples were in the obsolescent tuberculosis nodules of the apex of the lung with their caseous and even calcareous contents and firm fibrous envelopes. That these contain the living germs of the disease can be shown by breaking up the central matter and inoculating it into guinea-pigs, which in due time succumb to the active disease.

The war has shown that *such latent infection is common in surgical wounds.* The first, to our knowledge, to call attention to the subject during the war was Colonel C. J. Bond, a well-known surgeon of Lei-

cester, England. He recorded a series of cases in which by injury or surgical operations upon old wounds weeks and months after they had reached a quiescent and apparently completely healed stage, either tetanus, gas gangrene, or suppuration supervened, or cultures of pyogenic and other bacteria had been gained from the deep-seated and quiescent tissues, cicatricial and otherwise. These observations have been abundantly confirmed by Goadby who has made a singularly full and convincing study. It has to be realized that delayed operation upon wounds that have been the seat of a suppurative process is not without the danger of setting up once more the previous infection. In tetanus if a later operation has to be done it has become the rule to precede the operation by a prophylactic dose of antitetanic serum. The above affords a clear reason for this procedure.

THE PRINCIPLES OF TREATMENT OF PROJECTILE WOUNDS

Admitting all the newer and surer knowledge of the inflammatory process which we have gained during the war, it has also to be admitted that, for the benefit of the patient and his more rapid return to health, there has been the greater gain of a wide-spread recognition that suppurative inflammation is not to be encouraged but suppressed, and this by excision of the track of the projectile and all the damaged tissue, thereby bringing into apposition sound tissue to sound tissue with, wherever possible, closure of the skin. Remove all foreign bodies and all tissue that is dead or possibly contaminated, and close up. If in this process a few bacteria are left upon the exposed surfaces they will be attacked individually by the few leukocytes that migrate and will be subjected to the influence of the lymph which exudes; they do not matter if the surgeon has cleaned up the wound with proper surgical care.

Poor as was in general the hospital accommodation of the French armies, the greater virtue of the army surgical practice of the French was that with ambulant operating theaters they pushed their surgeons as near as possible to the front and operated whenever possible within the first few hours; operated often before shock showed itself and when the damaged tissues were relatively insensitive.

Slowly but surely through bitter experience the British, and following them the American, surgeons awoke to the significance of the French procedure, and this largely through the practice and teaching of Colonel H. M. W. Grey, R. A. M. C., from 1915 onward. In the last year of the war prompt and thorough removal of the damaged tissue became the rule wherever possible, to the material advantage of the patient, the notable shortening of the period of hospitalization, and the lessening of the mortality.

Nevertheless, this procedure was not possible in all cases. There still remained cases in which the loss of superficial tissue was so extensive, the parts exposed so vital, or the wounds already so old, with suppuration in full career, that prompt excision could not be considered. In such cases the principles here developed had to be put into practice.

And of these the most important was the realization that old pus is bad pus, favoring the multiplication of microbes and the continuance of the infection. Therefore the first duty of the surgeon is to get rid of it, whether it be absolutely or only relatively confined. Free discharge of pus is followed by introduction of fresh antibacterial serum into the wound, and so by material reduction in the number of bacteria in the wound. With the exudate there pass out fresh and active leukocytes, and these are of service in ingesting the serophytic cocci not destroyed by the exudate.

Wright extols the digestive powers of the leukocytes, dead and alive, and their capacity to dissolve dead tissue and slough, but, as the exhausted and dead leukocyte is far from being an unmixed blessing, it would seem better to remove that dead tissue by surgical measures.

That nature may be aided by washing out the wound is certain. The striking results obtained in many cases by Carrel and those who have employed his method and used his tubes and Dakin's fluid are beyond question. That method is of singularly great use in what may be termed straightforward wounds. Yet it has its disadvantages: through the constant attention demanded it is uneconomic, while, further, a large number of projectile wounds exhibit pockets in which inspissated pus collects. A simple current of fluid will not empty these pockets, and, as a consequence, they remain sources of continued infection and irritation. For such cases the water-tight "ebb-and-flow" method devised by the Taylor brothers is a distinct advance. The alternate distention of the wound and all its ramifications under positive pressure, followed by the suction effect of negative pressure, cleans a wound in a most efficacious manner. The rapid reduction of the surrounding redness and swelling is evidence of the good effects.

But, whether Carrel's or the Taylors method be used, if necrotic and infected bone and foreign bodies be left in the wound healing is painfully delayed.

We come back therefore to this: If the wound is recent and suppuration has not supervened, clean away all dead tissue without delay and bring the parts into apposition; if suppuration has supervened, get rid of the old pus, encourage free discharge and clean the parts, and at the earliest convenient moment open up the track of the wound, removing all dead tissue and foreign bodies.

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CHAPTER II

DISEASES CAUSED BY ANIMALS, INSECTS, AND REPTILES*

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RABIES

Rabies is one of the most interesting of the affections which occur in man. Fearful when fully developed, it has given occasion for one of the greatest triumphs of experimental pathology, and particularly of so-called vivisection. One of the lesser evils following in the wake of the Great War has been the increase in the number of cases in England and Europe. In England the disease was finally eradicated in 1902, and for sixteen years the quarantine imposed on imported dogs prevented its reintroduction. Owing to certain extraordinary conditions arising out of the war the quarantine broke down, and in August, 1918, rabies reappeared; 112 cases in dogs were reported during the remainder of that year; fortunately none of the 21 persons treated for bites from rabid animals succumbed. The report of the outbreak and much interesting data will be found in the Annual Report for 1918 of the Chief Veterinary Office of the Board of Agriculture and Fisheries.

In France the disease has reached more serious proportions. Martel[1] reports that the strict measures against rabies in Paris resulted in a drop from 846 cases in 1901 to 3 in 1913. The abandonment of their dogs by refugees and the absence of veterinarians, drawn into the war, have resulted in a recrudescence of rabies. In 1918 there were 411 rabid dogs killed in Paris, and there were 4 cases of rabies in man, and 350 persons taking the course of treatment at the Pasteur Institute of Paris. The ordinances in regard to keeping dogs muzzled and on a leash are not heeded now by the public, and in 1918 throughout France 1602 persons were bitten by rabid dogs, cats, cattle, or sheep, with 7 deaths, while 3142 cases of rabies in dogs were reported.

Diagnosis.—There is nothing new to report regarding the clinical signs and symptoms. The physician must be careful to make a correct diagnosis. Perroncito[2] calls attention to the occurrence of "pseudo-rabies" of dogs in Italy caused by intestinal worms, and the "atypical rabies" caused by streptococci or pyocyaneus infection. The true disease manifests itself oftenest in the course of the second or third month after infection, less frequently after the third month, and rarely after the sixth month. It is important to remember, however, that the saliva of a dog about to become rabid is infective for a few days before it shows any apparent symptoms of the disease.

Several cases have been reported in which agitation, distress, and periods of delirium preceded the classical symptoms by a number of days. One observer calls attention to pruritus as an early symptom.

*Supplementary to Chapter XIV, Vol. I, p. 530, and Chapter XCI, Vol. VI, p. 81.

Negri Bodies.—The finding of these bodies in the brain and medulla of suspected animals is usually considered sufficient justification for a positive diagnosis except in the early stages of the disease. Harvey and Acton[3] are of the opinion, however, that Negri bodies are not truly specific of rabies, although there is undoubtedly a very close correlation between the presence of numerous Negri bodies and rabies. Hardenberg and Underkill[4] take up this important question and report the results of an investigation of 453 brains and ganglia. They conclude that while "Negri-like" bodies may occur in smear and reaction preparations from brains of animals dead from other causes than rabies, true Negri bodies are only present in the central nervous tissue of animals which were suffering from rabies at the time of their death.

Prognosis.—As stated in the previous articles (Vol. I, p. 530, and Vol. VI, p. 80) rabies is practically certain to result fatally if it once develops. The records of the "Pasteur" treatment eloquently prove its efficacy. At the Pasteur Institute, Paris, between the years 1886 and 1918 a total of 39,721 persons received antirabic treatment (dried cord system), with 0.39 per cent. failures. In 1886 the failures were 0.94 per cent.; in 1887, 0.79 per cent.; in 1888, 0.55 per cent., and in 1894, 0.5 per cent. In three of the years—namely, 1908, 1912, 1913—there were no failures, and in all the other years they were under 0.5 per cent., and in four instances under 0.2 per cent.

During 1918 no less than 784 persons received antirabic treatment at the bacteriologic institute in Lyons, France. More than half of them had been bitten by animals actually demonstrated to have been suffering from rabies. There was not a single death among the patients treated. Since 1900 more than 11,000 persons from the vicinity of Lyons have received antirabic treatment. Only 10 persons have failed to be protected, representing a mortality of 0.08 per cent. At the Institute Pasteur, Algiers, the report for 1918 states that 1907 persons underwent the antirabic treatment during that year. Of this number, 15 did not follow the full course of treatment, the dog having been found to be healthy, and 12 others discontinued the treatment; 6 cases proved fatal, but in only 1 of these did death take place more than fifteen days after the date of the bite; consequently, in only one could the treatment be said to have failed. This gives a mortality of 0.05 per cent. On looking into the figures, we find that of 56 persons bitten by animals found by inoculation to be rabid, 1 died; of 498 bitten by animals diagnosed by veterinary surgeons to be rabid, 2 died; while of 1208 persons bitten by dogs merely suspected to be rabid, 3 died. The spinal cords of 47 animals were received at the laboratory, and of these, 18 yielded positive results on examination, 20 were negative, and 9 were too decomposed for proper observation. Of the rabid animals, 108 were dogs, 71 cats, 5 jackals, 4 horses, 1 mule, 8 asses, 1 calf, 1 gazelle, 1 pig, 1 rabbit, and 4 rats.

Treatment.—Local treatment cannot be relied upon to prevent infection in all cases, but if instituted within three hours the chance of infection is diminished and general treatment made easier and more

certain of success. Sucking the wound is dangerous to the person practising it; excision only opens up a wider field for infection. The wound should be cauterized with pure carbolic acid. According to Semple, this chemical is preferable to "fuming" nitric acid, the remedy usually advised. The carbolic acid should be well worked into the wound and then washed out with water or with alcohol. A wet dressing should be applied after the cautery has been used. Caustic soda or potash, nitrate of silver, or tincture of iodin may be used if the above cannot be obtained. Any antiseptic is better than none. Water is better than nothing.

Antirabic Treatment.—Haste is imperative. Should the virus succeed in reaching the nerve-centers before immunity has been conferred death is inevitable. There are three principal methods by which specific treatment may be given, namely, (1) Pasteur's dried cord method, (2) Högyes' dilution method, (3) carbolized vaccine. The original method of Pasteur and its later modifications is familiar to every one. The Högyes modification is based on the fact that Pasteur's attenuation of cords by drying effects a numeric destruction of the organisms, and the same result can be attained by diluting the living and virulent virus and injecting the higher dilution (1 : 6000 or 1 : 100) at first, and progressing day by day until the low dilution is reached (1 : 500 or 1 : 100).

The use of dead rabies vaccine seems to have originated with Semple in 1910. The method of preparation is as follows:

The vaccine is prepared from the fresh brain, medulla, and spinal cords of rabbits which have died from rabies after inoculation with "fived" rabies virus. The material is finely ground down in 8 per cent. dilutions in sterile normal saline solution to which has been added 1 per cent. carbolic acid; it is then filtered into a sterile glass receptacle through fine muslin to remove any particles of fibrous tissue which may be present, and kept at a temperature of 37° C. for twenty-four hours. At the end of this period the virus is dead; it is now diluted with an equal volume of sterile normal saline solution, filled into suitable bottles (20 c.c. bottles), capped with rubber caps, and sealed with melted paraffin wax. Aseptic technic is observed throughout. On the preparation of a "brew," two tests are carried out—one for sterility and the other by inoculating a rabbit subdurally to prove that the virus is dead.

It will be noted that this method of preparation gives a 4 per cent. dilution of dead virus in 0.5 per cent. carbolic acid normal saline solution—a dilution suitable for treatment purposes, or which could be still further diluted if considered necessary.

This vaccine is now being used in England, and persons receiving antirabic treatment are inoculated daily, and for a period of from fifteen to eighteen or twenty-one days, according as to whether light, medium, or intensive treatment is considered necessary. Each case should be dealt with on its own merits. The points taken into consideration in determining a line of treatment for any given patient are:

number of bites, depth and severity of bites, position of the bites—such as whether on the head, face, or neck, or through the exposed skin on any other part of the body; whether through the clothing; whether the wound was treated early and efficiently; the evidence to hand as to whether the animal which inflicted the bites was rabid; and, most important of all, the time which elapsed before the patient came for treatment.

Semple states that at the Pasteur Institute of India between the years 1912–16 a total of 2009 Europeans received antirabic treatment with carbolized antirabic vaccine, with 0.19 per cent. failures.

Harris[5] has published a modification of the Pasteur method founded on Shackell's investigations on the effect of desiccation *in vacuo* at a low temperature. He reports 1159 cases treated, with but 2 failures, in both of whom the disease developed before the possibility of antibody formation.

"The preparation of the material is as follows: Brain and cord, stripped of pia and blood-vessels, are ground in a mortar into a homogeneous, thick, paste-like mass; carbon-dioxid-snow, collected from a tank into a sterile cloth, is added to the paste until freezing is complete and until further grinding reduces the mass to a fine powder. This powder is transferred quickly to a cold beaker and placed in a Schibler's jar which has been submerged in a mixture of salt and ice (—18° C.). In the upper part of the jar is a beaker of concentrated sulphuric acid. A vacuum of less than 2 mm. is produced and the powdered brain is kept at —18° C. in the salt and ice until desiccation is complete. A single brain and cord will be completely dehydrated in from thirty-six to forty-eight hours."

A more detailed description is given by Harris in earlier papers, and his article should be consulted for many references to antirabic treatment. Semple[6] also discusses the various methods in detail.

Quinin and Urea Hydrochlorate.—In 1913 Moon reported the successful use of this drug in dogs suffering from rabies. In the same year Harris[7] reported a human case successfully treated. The experimental results of Moon have not been confirmed by others, nor has the use of this drug been proved efficacious in 5 or 6 human cases where it was used. Salvarsan and neosalvarsan have also proved unsuccessful.

"Treatment" Paralysis.—Though hundreds of thousands of persons have been treated by the Pasteur method, there are records of only 150 cases in which paralysis has followed its use. Levy[8] has collected the cases of isolated facial paralysis, 10 in number. The lesion appeared as early as the seventh day or as late as the thirty-first day after beginning treatment. It may be bilateral. Nine of the 11 cases recovered. Fielder[9] explains that in most of the cases, at least, the symptoms are caused not by street virus infection, modified by the treatment, but by the treatment itself, either through the medium of fixed virus infection or through the action of a toxin, or both. In any event, there must be a special idiosyncrasy on the part of the patient. Otherwise the cases would be enormously more frequent than they are.

Control of Suspected Dogs.—Semple offers the following practical suggestions: 1. The dog should not be destroyed, but should be kept under control and close observation for a period of ten days from the date of the bite, and in the event of any symptoms of ill health or departure from its normal habits, a report should be made to the police at once. If at the end of the ten days' observation period the dog is still healthy and free from any symptoms of rabies, the person bitten has nothing to fear as regards infection; even though the animal should develop rabies on the eleventh day or any subsequent date, no antirabic treatment would be required.

2. If the dog showed signs of rabies within ten days from the date of inflicting the bite, the person bitten should receive antirabic treatment as soon as possible after the condition of the dog has declared itself.

3. A person severely bitten on the head, face, or neck would not be justified in waiting ten days to know whether the animal was infective or not. A delay of ten days, or even four to five days, in a case of that kind might be disastrous, as it might then be too late for successful treatment; the safest course to adopt in such cases would be to commence antirabic treatment at once, and as soon as it became evident that the dog was not infective the treatment should be discontinued. In a rabies-infected district a person bitten by a stray dog which subsequently disappeared and was not again seen or heard of should receive antirabic treatment as a precautionary measure.

4. It is evident that in a rabies-infected area it would be a mistake to destroy a healthy looking dog immediately after it had bitten anyone, because then all information regarding his condition would be lost unless the carcass or a portion of the brain was sent to a laboratory for experimental tests, which would mean a delay of from four to five days, up to a period of three weeks, or possibly longer, according as to whether Negri bodies were looked for and found, or the inoculation of an animal carried out.

BITES AND STINGS OF INSECTS

The description of the results of bites from scorpions, centipedes, and spiders (tarantula) given in Volume I, p. 538, is quite brief. A recent writer, Coughlan,[10] states that many of these cases were seen along "the border" among the men of the National Guard stationed there in 1916. Red ant bites were numerous, and when a person was bitten in a number of different places an annoying irritation and smarting sensation was produced. Tincture of iodin painted over the area relieved the condition in a few minutes. Scorpions caused many troublesome bites, a small white area appearing, which required, as a rule, several applications of tincture of iodin. Of the many varieties of spider bites, the most severe was that caused by the tarantula. They produced white, raised, swollen areas, about an inch in diameter, with a smarting, stinging sensation. The earlier bites were treated with iodin, but later more instant relief was obtained from the use of equal parts of spirit of ammonia and water applied as a wet dressing. Centipedes were not numerous. The bites were incised and drained and

dressed with wet bichlorid. No constitutional symptoms resulted. The insects met with by Coughlan seem to be much less virulent than those in Mexico. Reference has been made in the previous volume to the fatal character of some of the scorpions and tarantulæ.

Mills[11] states that "there is no doubt that many deaths ascribed to scorpion poisoning are the result of repeated poisonous doses of tincture of iodin, carbolic acid, and similar drugs given by the numerous 'practicantes,' who serve as physicians in the villages, and many people are carrying around extensive and most disfiguring scars from the local applications of every known escharotic."

That deaths can occur from scorpion sting is shown by a number of animal experiments and one human case. The symptoms observed were as follows: Numbness, formication, and a sense of thickness of tissue began immediately in and about the wounds, and spread rapidly, chiefly upward toward the chest. He vomited once, felt anxious and very nervous, and complained that his tongue felt "too big for his mouth." Saliva and nasal mucus increased, the eyes became suffused and photophobic, and the sensation of an increasingly large ball in the throat caused him to swallow frequently, to clutch at his neck, and to try to dislodge the distressing body with his fingers. Within about two hours he was very dyspneic and cyanosed, the respiration was 48 and the pulse 136. The muscles of his legs, arms, and face felt stiff and his head ached badly.

According to Mills the treatment of scorpion sting varies with the severity of the symptoms. In general it consists of:

1. Simple incision and the local use of evaporating lotions.

2. In severe cases incision, combined with lumbar puncture, which may be repeated if necessary, and the repeated hypodermic injection of scorpion blood to total about 1 c.c. per kilo of body weight.

3. The internal administration of stimulants, such as black coffee and aromatic spirits of ammonia, or hypodermic and rectal stimulation if unconscious.

However, Mills remarks that at present the use of scorpion's blood in quantity is impractical. The rationale of its effects is as follows: Scorpion's blood contains protective substances which render the scorpion immune to its own poison. These substances, if injected early and in sufficient quantity, aid markedly and promptly in relieving the urgent symptoms in human beings following scorpion sting.

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CHAPTER III

ANTHRAX*

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During the six years from January 1, 1910 to December 31, 1915 no fewer than 132 deaths from anthrax were officially reported in the United States registration area, which covers less than two-thirds of the total population of the country. The probable ratio of deaths to the total number of cases is believed by Andrews[1] to be about 20 per cent., this figure being in substantial accord with that of the British authorities, Bell and Legge.

As stated in the previous chapters (Vol. I, Chapter XIII, p. 503, and Vol. VI, Chapter XC, p. 72) anthrax in man is, in the great majority of cases, of occupational origin. The following industries are the most important: Leather, animal hair and bristles, wool, horn, and bone. Longshoremen, porters in warehouses, and other workers engaged in transportation of the above materials are frequently infected. Full reports upon the occurrence of outbreaks of anthrax in the United States will be found in the exhaustive bulletin prepared by Andrews.

In 1915 and 1916 a number of widely scattered British cases of the disease were definitely traced to shaving brushes. In the United States anthrax has apparently been gaining in frequency, and has become a cause of increasing concern to health officers in many places. Many cases of anthrax directly traceable to infected shaving brushes have been reported from the armies of the United States as well as Great Britain. A full report may be found in the Public Health Reports (U. S. A.) for July 12, 1918, or in a collective abstract in the Review of War Surgery and Medicine for March, 1919.

Diagnosis.—As Regan well says, "local treatment in order to effect a cure must antedate the onset of an anthrax septicemia." This means early diagnosis. The symptomatology has been emphasized in the earlier volumes, but the following description of the local lesion by Schwartz[2] is very accurate: "The first day it usually resembles a furuncle, but should it be anthrax, there is a flaccid vesicle with turbid content, while a furuncle has a yellow pus content. The second and third day, when the malignant pustule develops still further, it becomes more characteristic. It has a black necrotic center, usually surrounded by vesicles at the edge, and the base is indurated (button-like); the size is $\frac{1}{3}$ to $\frac{3}{4}$ inch, and the surrounding area is edematous. There is inflammation of the surrounding lymphatics. At this stage it should not be mistaken for any other lesion. It should be mentioned

* Supplementary to Chapter XIII, Vol. I, p. 503, and Chapter XC, Vol. VI, p. 72.

that often at this stage (third or fourth day) the bacilli are no longer found in the pustule at the usual place of examination under the crust, but pyogenic bacteria and streptococci are found. However, the bacilli can be found in the indurated lower layers (rete mucosa). Further differentiation from furuncle is that the anthrax pustule does not contain pus, which is always present in furuncle; the latter is more painful, is larger than an anthrax pustule, its base is not indurated, and there is no surrounding edema. It is more difficult to differentiate anthrax from certain cases of carbuncles in which the center dries down to a gangrenous crust. Here there is a marked resemblance to a malignant pustule (anthrax), but again there is no surrounding edema, etc. At times the pustule is to be differentiated from glanders; the anthrax edema is to be differentiated from erysipelas and diffuse phlegmon."

Physicians suspicious of anthrax pustule should at once make smears and cultures without waiting for anthrax septicemia to develop. If the patient's vocation brings him in contact with hides, leather, wool, or bristles, or the pimple has followed a "shaving wound," we should be doubly suspicious.

Meningitis in Anthrax.—In a few cases recently reported the symptoms of meningitis were present from the beginning. Gilmour and Campbell[3] report the case of an officer who nicked himself in the cheek; forty-eight hours later the left side of the face and neck became swollen, and shortly afterward headache, chilliness, and fever were complained of. Respiratory symptoms ensued and vomiting occurred. The headache became more intense and there was pain in the back and limbs. Delirium and convulsions followed, and death occurred within eighteen hours of the onset. A tentative diagnosis of cerebrospinal fever was made and lumbar puncture performed; the fluid was teeming with anthrax bacilli.

A case was reported by Delater and Calmels[4] with similar symptoms and death in about sixteen hours after onset. At autopsy the meninges and cerebral convolutions were covered by a network of dilated veins filled with very black blood. Another case is reported by Angevine.[5]

Blood Studies in Anthrax.—Laboratory workers have found that as the guinea-pig is highly susceptible to anthrax this animal should be used in preference to white rats, which possess a high degree of immunity to B. anthracis. If hemorrhagic streptococci are present in the lesion the animal may be rapidly killed by this and the diagnosis obscured. Dennett[6] calls attention to the distinctive appearance of the anthrax colonies. Under lower power the colonies appear as dense, irregularly rounded masses from which spread parallel, wavy strands, which under high power are seen to consist of chains of bacilli, each bacillus containing an oval, glistening body in the center. He also notes that the leukocytosis runs concurrently with the blood-culture findings, *i. e.*, a positive culture is associated with an increased white cell count. The eosinophil count is in inverse proportion to the severity of the infection.

The **treatment** of anthrax is now on a more satisfactory basis. The diagnosis must first be made by smear, culture, or inoculation of guinea-pigs. The next step is the immediate giving of antianthrax serum. The pustule itself should then be rapidly excised with knife or cautery under local or gas-oxygen anesthesia; the wound should not be sutured, but treated with dichloramin-T or flavine. Dudley injects 8 per cent. phenol into the tissues around the lesion before excision and paints the raw area with pure phenol immediately neutralized with absolute alcohol. He uses wet dressings and prefers an ice-bag to the heart. Both he and Schwartz advise painting the pustule with collodion prior to operation to avoid contamination. Many writers have simply used hot boric solution dressings. At any rate, mutilating operations should be avoided.

Antianthrax Serum.—In previous volumes the use of Sclavo's serum has been referred to. It has been used but little in this country as compared with Europe. Recently the Department of Agriculture has prepared a serum-globulin derived from sheep. This preparation is described by Eichhorn, Berg, and Kelser,[7] and they state it has been used with highly satisfactory results. The curative dose is 40 c.c. administered subcutaneously in four or five places. After an interval of twenty-four hours a further injection of 25 c.c. may be given, repeated as often as necessary. Larger intravenous injections may be given in advanced cases. The dose of the globulin preparation is based on its proportional concentration, and is usually from 10 to 15 c.c., which can be safely given intravenously. With other types of protein absent the globulin preparation is superior to ordinary serum, inasmuch as anaphylactic reaction is minimized. In a number of cases of anthrax in man treated at Bellevue Hospital, New York, it was found that a marked lowering of the temperature and reduction of the edematous swelling followed the first injection of the serum. The local use of antianthrax serum has been tried by Ludy and Rice,[8] who infiltrated the area about the lesion with 50 c.c. of the serum, and by Regan,[9] who injected 12 c.c. about the pustule. He also gave 30 c.c. intramuscularly into the buttocks. Both were repeated in twenty-four hours. Regan advises that the needle be inserted just outside the margin of the lesion, and directed toward the subcutaneous tissues at the base of the eschar. The needle may have to be introduced at three points in order to encircle the pustule. The serum is introduced very slowly, the dosage varying from 10 to 15 c.c. It should be administered once daily until the local process is controlled, usually two or three injections being sufficient. The serum should also be given intramuscularly or intravenously. Dudley[10] recommends 35 c.c., injected intravenously, followed within from eight to sixteen hours by a second dose, given intramuscularly or intravenously. This dose is repeated again if necessary.

Beef Serum.—The Argentine Republic, being a great cattle-raising country, has suffered more severely from anthrax in recent years than any other part of the world. Kraus and his co-workers have published

numerous reports during 1916 and 1917 advocating the use of beef serum. He has had 146 cases with only 1 death. In his last communication[11] he advises subcutaneous injection in doses of from 30 to 50 c.c., and repeats the injection in twelve, twenty-four, or thirty-six hours, as indicated. Very seldom are more than two or three injections required. In the extremely severe cases he advises to inject the serum by the vein. The serum is heated twice to 56° C., and it only exceptionally induces serum sickness. Even when the case seems mild he warns not to use a smaller dose than 30 or 50 c.c. Recently Hyman and Leary[12] have published an excellent résumé of the serum treatment of anthrax, and refer fully to the method of Kraus.

Prophylaxis.—The present status of the problem of disinfection is set forth in detail by Andrews,[1] and space does not permit any details. The appreciable increase of anthrax in England has also led to investigations.[13] It would seem, however, that so far no certain means of destroying the spores by heat or antiseptic solutions without injuring the commercial value of the hides, wool, or other material have yet been discovered. Education of employer and employee of the danger of these materials, their proper handling, and the early recognition of the pustule should be encouraged. In regard to shaving brushes Public Health Reports for May, 1919 states that: "After a careful survey of the industry and the performance of a few tests under conditions approaching those in manufacturing establishments it was decided that either boiling or steaming afforded a satisfactory means of treating the hair."

For the sterilization of brushes the following procedure is believed to be effective:

The brush should be soaked for four hours in a 10 per cent. solution of formalin (by formalin is meant a 40 per cent. solution of formaldehyd). The solution should be kept at a temperature of 110° F. and the brush so agitated as to bring the solution into contact with all hair or bristles.

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CHAPTER IV

SURGERY OF THE SKIN*

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Burns may occur from the effects of hot air, hot liquids or steam, from exposure to chemical rays of light, and from acids, alkalis, electricity, *x*-rays, radium, and caustic substances of various kinds. During the recent war many severe burns occurred from the use of "mustard" and other irritant gases.

The chief indications in treatment are to combat shock, to eliminate the toxins developed, to prevent infection, and to heal the denuded areas. Pfeiffer (Das Problem des Verbrennungs Todes) alleges that death results from an auto-intoxication due to the destruction of protein tissue at the site of the burn and the consequent absorption of the toxins. Risley[1] deems it vital to first determine the degree of shock and to take active measures to combat it. In severe shock, especially in children, the immediate removal of the clothing and the dressing of the burns may increase the shock to such an extent as to lead to a fatal termination. A liberal dose of morphin should be given, subcutaneous salt infusion and rectal shock-enemata administered, and heat applied. If the patient does not improve within a half-hour, he should be put into a continuous hot bath (90° to 110° F.) without the removal of clothes. The bath should contain salt in the strength of the normal saline solution or boric acid may be incorporated therein. After the bath the clothing may be cut away, but not before. If improvement sets in, experience shows that exposure of the naked patient to an atmosphere of 110° F. has been followed by good results.

Local Dressings.—In superficial burns great relief will be experienced from the use of picric acid solution of the following composition:

℞. Acidi picrici 1.0
Spts. vini recti ..... 25 c.c.
Aquæ ..... q. s. 100 "

This may be painted over the affected parts. Lee and Furness[2] recommend the use of dichloramin-T. They employ a single layer of gauze and then spray the solution incorporated in eucalyptus oil upon it. "No other dressing should be applied, and the usual technic of the open-air treatment of burns should be followed."

A great improvement in the treatment of burns has been brought about by Barthe de Sandfort. He advised a new formula for an occlusive dressing which was a great advance on the old paraffin treatment. Unfortunately, the composition of this preparation has been kept secret.

*Supplementary to Chapter XXX, Vol. II, p. 616, and Chapter CVI, Vol. VI, p. 237.

Lieut.-Col. A. J. Hull,[3] of the British Army, after considerable experimentation, produced a preparation which is highly satisfactory. In the Brit. Med. Jour., Dec. 15, 1915, his latest formula, known as No. 7 paraffin, is given as follows:

Resublimed betanaphthol	0.25 per cent.
Eucalyptus oil	2.0 "
Olive oil	5.0 "
Paraffinum molle (or vaselin)	25.0 "
Paraffinum durum	67.75 "

Wash the burn with a solution of acroflavin or proflavin, 1 : 1000. Dry it by fanning or laying dry gauze on the surface. (A Shelton electric hot-air drier or a Hamilton-Beach fan is best, although an ordinary electric fan or a common hand fan may be used.) The paraffin mixture at 55° to 60° C. (131° to 140° F.) is then applied by a spray atomizer or, if this is not at hand, with a broad sterile camel's-hair brush. It is important to apply a thick layer of paraffin.

A thin layer of cotton-wool (pressed thin between layers of paper) is applied over the wound after the first layer of paraffin. Then the layer of wool is sprayed with paraffin. Apply a wool bandage over the dressing. The dressing should be changed at first daily, later every other day. At the second dressing the dead layers of skin are removed. Burns treated by this method occasionally become sluggish. Hull advises the scarlet-red paraffin when burns have become clean. A great acceleration of healing is claimed. The formula of scarlet-red paraffin is as follows:

Scarlet-red	0.2 per cent
Eucalyptus oil	2.0 "
Olive oil	5.0 "
Adeps lanæ hydrosus	4.0 "
Paraffinum molle	21.0 "
Paraffinum durum	67.8 "

In the Western Pennsylvania Hospital the following formula is used:

Paraffin	70.0
Liquid petrolatum (U. S. P.)	3 c.c.
White beeswax	10.0
Rosin	7.0
Resorcinol	0.2
Sudan	0.05
Alcohol (95 per cent.)	10 c.c.

The petrolatum and paraffin are melted together. The resorcin is dissolved in the alcohol and slowly added to the paraffin mixture while stirring. The heat is continued and the alcohol evaporates. The beeswax is added and stirred until melted. The rosin is then added with stirring, the heat being continued.

Another formula said to be satisfactory is:

Paraffin (49° to 55° C.)	97.5 per cent.
Olive oil	1.5 "
Asphalt	0.25 "

The compound should be melted at about 47° C. (117° F.) and applied at a temperature of about 60° C. (140° F.).

Sollmann and Beiter[4] state that the application of the ordinary melted paraffin to the wound is too painful, and recommend spraying with petrolatum liquidum. The cotton film is then applied and the melted paraffin painted or sprayed on it as usual.

Sherman,[5] who has had a large experience in the Carnegie Steel Company of Pittsburg, presents an admirable paper on The Paraffin-wax or Closed Method of Treatment of Burns. Sherman and his associates during the past seven years have treated 31,448 first and second degree burns, and 4683 third degree burns; 3000 cases have been treated by the paraffin-wax method. This vast experience enables him to speak with authority. He states that very few who have witnessed the paraffin-wax treatment at first hand have failed to acknowledge its unquestioned superiority over every known method. "After the first twenty-four hours the patient is free from pain in the vast majority of cases. Scar tissue is infinitely less than with any other method, and does not have the tendency to contract, so that the frightful disfigurement and loss of function are practically eliminated. Even the largest burns can be dressed in five to eight minutes. Any paraffin-wax, which is neutral and has sufficient elasticity and ductility so as not to crack after it has been applied, will give good results." Sherman makes the following practical suggestions:

"(*a*) At the first dressing burns should not be scrubbed with antiseptic solutions. The tissues are sterile as a result of the burning, and nothing is to be gained by further traumatizing the tissues. Apply the wax at once; merely sponging will not sterilize the wounds if they are infected, regardless of the antiseptic solution used.

"(*b*) Strong antiseptic solutions should not be used in cleansing the burn or granulating tissue at dressing; they should be comparatively weak. The strong antiseptic solutions tend to retard repair. Saline, boric, chlorazene, flavin, brilliant green, or chloramin can be used in weak solution (preferably in an atomizer).

"(*c*) The instructions should be carefully followed. Absorbent cotton should never be applied directly to the burn or wound, as it tends to stick, causing a burning sensation which is very uncomfortable to the patient. The wax applied alone is a soothing and comfortable dressing.

"(*d*) The fetid odor and gray appearance of the wound when the shell is removed should not cause any undue anxiety. After the seropurulent fluid has been washed away and the sloughing tissues separate, granulations with rapid proliferation of epithelium take place.

"(*e*) It is impossible to burn the patient when the atomizer is used. The wax should not be applied at a temperature over 150° F. where the brush is used.

"(*f*) In third and fourth degree burns, with great loss of tissue, granulations should be sterilized with the Carrel-Dakin method and skin grafted at the earliest possible opportunity. Grafting is not necessary unless there has been very extensive destruction of tissue.

"(*g*) The application of the heated wax encourages the flow of lymph

and protects the capillaries and granulation tissue from trauma, which is favorable to rapid repair."

Cicatrices or Scars.—Cutaneous scars may result from a great variety of destructive processes involving the skin. They invariably connote a destruction of a portion of the corium or true skin. They vary greatly in size, shape, and depth, depending upon the nature of the cause that gave rise to them.

In past years smallpox was a common cause of multiple facial scars; these scars were of a pitted or pocked character—therefore the old English name of "the pockkes," which was applied to the disease.

Many ulcerative or necrotizing dermatoses may give rise to scars, such as syphilis, tuberculosis, leprosy, epithelioma, blastomycosis, sporotrichosis, actinomycosis, carbuncles, boils, etc. Under some circumstances scarring may take place without ulceration; it may result from the absorption of cellular infiltrate in the skin, as occurs in lupus erythematosus. In this affection the scarring is of a whitish, atrophic character. Atrophic scars may also result from overdistention of the skin, as is seen in "linea albicantes" of pregnancy and of corpulence.

Some of the most disfiguring and distressing cutaneous scars may result from burns. These are prone to be dense and fibrous, with linear bands and deep depressions. **Hypertrophic scars** and **keloids** occur in individuals in whom there is a predisposition to fibrous overgrowth. This, of course, is notably the case in the negro race.

Treatment.—The disfigurement of syphilitic scars resulting from broken-down cutaneous gummata may be considerably mitigated by the use of a firmly applied mercurial plaster to the wound during and after the final stages of cicatrization and epidermization. The pressure flattens out the resultant scar.

Keloids and *hypertrophic scars* are best treated by excision, followed within a few days by the vigorous application of the *x*-rays.

Smallpox scars may be mitigated by treatment, which sets up a severe inflammation of the entire affected area to such a degree as to lead to seropurulent exudation. This is followed by the use of a plaster to effect as much pressure as possible. I have seen patients treated by irregular, advertising practitioners by this method with undoubted beneficial results. I suspect that an acid of the nature of trichloracetic acid is used. The severe inflammation tends to vascularize as much as possible the scar tissue.

I have obtained good results in the treatment of acne scars by a method based upon the same principle. This consists in the use of *solid carbon dioxid* applied over the affected areas, with moderate pressure, for about thirty seconds. A pronounced inflammation associated with vesication follows. I have also succeeded in flattening hypertrophic scars by this method. Acne patients who have had considerable *x*-ray treatment must be treated with circumspection, inasmuch as the vascular degeneration resulting from the roentgenization makes the skin more vulnerable to ulceration.

Carter and Shefford[6] have obtained good results in the treatment of

facial scars resulting from *war injuries* by the use of *ionization.* They employ the alternating current derived from the city power, run through a motor transformer, so as to yield a constant current of 100 volts E. M. F. This is conveyed to the patient through a distributing board, fitted with a wire resistance rheostat to permit variations of strength of the current. It is also provided with a milliamperemeter which registers the current strength. The electrodes consist of small zinc plates about 2 inches square, which are applied to the skin over sixteen to twenty-four layers of folded lint. The lint is cut about ½ inch larger all around than the metal pieces in order to avoid possible burning of the skin by contact with the electrodes. The lint pad of the negative or active electrode is saturated with salt solution, or solution of potassium iodid or sodium salicylate, in 1 to 2 per cent. strength in hot distilled water. The pad of the positive pole is soaked in hot water containing a trace of salt. The negative electrode is placed over the cicatricial area, while the positive is usually placed under the chin. Most of the work of Carter and Shefford was carried out in cases where there was damage to the masticatory muscles. The treatment lasted from thirty to fifty minutes daily when the condition of the skin permitted, and on alternate days when the skin was sensitive. The current is turned on very slowly, starting with 2 to 3 milliamperes, gradually working up, according to the patient's tolerance, to 15 or 20 milliamperes. At the end of the treatment the current is gradually reduced before contact is broken in order to avoid the unpleasant shock to the patient.

Hollande[7] records the use of ionization of facial cicatrices due to wounds. He advises that the strength of the current (220 volts continuous current) should not exceed 10 M. A., as the weaker the current, the more rapid the ionization of the potassium iodid upon the scar tissue. The positive pole is moistened with the potassium iodid solution. Treatments lasting twenty to twenty-five minutes are usually given each day for a period of three to four weeks or longer.

In "soft" scars, with disappearance of the corium, cures are common; even with fibrosis scars, with thickening of cicatrical tissue, 37 out of 43 were cured.

Carter and Shefford believe that the iodid as an electrolyte is apt to cause irritation of the skin, and prefer sodium chlorid, which they believe to be more effective in softening the scars. The negative pole as electrode was preferred because of better results, doubtless due to an induced hyperemia which lasted an hour or two after treatment. The authors believe that the benefit from the treatment is due *to active* bombardment of the tissues during the passage of the current, and not to the circulation of the ions in the blood.

Ivy Poison—Dermatitis Venenata.—Schamberg has recently advocated a method of desensitizing persons subject to ivy poison. By taking internally an extract of the offending plant the individual becomes for a time resistant to attacks. The drug is dispensed as follows:

℞. Tr. rhus toxicodendri..... 1 c.c.
Spts. vini rectif..... 5 "
Syrupi aurantii.....q. s. 100 "

The patient is instructed to take the mixture in a half-glass of water after meals, as follows:

	Breakfast.	Lunch.	Dinner.
First day:	1 drop	2 drops	3 drops
Second day:	4 drops	5 "	6 "
Third day:	7 "	8 "	9 "
Fourth day:	10 "	11 "	12 "
Fifth day:	13 "	14 "	15 "
Sixth day:	16 "	17 "	18 "
Seventh day:	19 "	20 "	21 "

When this dosage has been reached, for purposes of convenience and simplicity the patient takes a *teaspoonful* in a half-glass of water merely once a day. This should be continued throughout the ivy season.

Experience has taught that the immunity (if one may call it such) established after one month's administration will persist for about a month afterward. After this susceptibility is prone to return.

Treatment of Attack of Ivy Poison.—The same mixture appears to exert a favorable influence upon attacks of ivy poisoning in preventing extension of the process, and in abbreviating the duration of the attack. In order to bring the patient more quickly under the influence of the drug it is administered as follows:

	Breakfast.	Lunch.	Dinner.
First day:	2 drops	4 drops	6 drops
Second day:	8 "	10 "	12 "
Third day:	14 "	16 "	18 "

Then, once a day, a teaspoonful well diluted.

It is, of course, necessary to establish the fact that the ivy has been the cause of the dermatitis. The rhus toxicodendron tincture would probably be of no value in treating unrelated primrose or other forms of plant poisoning. It is more than likely, however, that desensitization against these poisonous plants could be accomplished by using extracts of primula obconica, etc., in the same manner as detailed above.

The local application which has given me the best results is as follows:

℞. Resorcinolis..... 4.0
Acidi borici..... 4.0
Sodii thiosulphatis..... 4.0
Zinci oxidi..... 10.0
Aq. hamamelidis..... 60 c.c.
Aquæ.....q. s. 180 "

Molluscum contagiosum, or *molluscum epitheliale,* is a disease characterized by formation upon the skin of pin-head to pea-sized or larger, smooth, semiglobular, waxy white, or pinkish elevations. The growths have a central opening from which a cheesy secretion may be expressed. The lesions are usually situated about the eyelids, cheeks,

or chin, but may occur upon any part of the cutaneous surface. The disease is transmissible and not infrequently occurs in epidemics in schools, gymnasiums, and asylums.

Etiology.—The disease is carried by direct or intermediate transmission from one individual to another. Epithelial mollusca occur at times upon the eyelids of pigeons and fowl, and this may be a source of infection.

Wile and Kingery[8] have recently made an important contribution to our knowledge of this subject. They have transmitted the lesions to volunteer human subjects by employing a filtrate of the débris of cureted lesions, the filtrate being sterile upon ordinary culture-media. Typical lesions were produced which, under the microscope, exhibited the characteristic structure of molluscum tumors.*

Treatment.—The tumors may be destroyed by incision, expression of the contents, and cauterization of the base with phenol or the stick of nitrate of silver. A simple and often effective treatment consists in boring into the central opening with a toothpick dipped in carbolic acid or iodin. An excellent and rapid method of removal is by cauterizing with the electrocautery or the small tipped Paquelin cautery.

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* Wile and Kingery have definitely proved that molluscum contagiosum is due to a filterable virus.

CHAPTER V

SYPHILIS *

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The Early Diagnosis of Syphilis.—We cannot hope to make any considerable progress in the prevention of syphilis and the consequences of syphilis until two movements are carried out: first, the education of the public regarding the infection, so that individuals with a genital lesion will go to a reputable physician, and, second, the education of the medical profession concerning the available means to an early diagnosis of syphilis.

The laboratory aids to an early diagnosis of syphilis are the demonstration of the Spirochæta pallida by means of the dark-field examination and the Wassermann reaction.

The Dark-field Examination.—In an untreated and uninfected chancre the dark field is positive in 100 per cent. The sore should be dressed only with physiologic sodium chlorid solution, boric solution, or simply warm water. No antiseptic treatment should be instituted until the diagnosis is established beyond a doubt. This is especially important because local treatment with a spirocheticidal drug greatly decreases the percentage of positive findings. The commonly used spirocheticidal drugs for local application are silver nitrate, mercury, iodin, copper sulphate, and iodoform. Spirochetes become very scanty on the surface of the chancre after one application of silver nitrate, which is the most powerful local spirocheticide. The dark-field examination becomes negative almost uniformly after one application, although the discontinuance of its use allows a reappearance of the spirochetes on the surface. Two daily applications of calomel powder cause the spirochetes to disappear from the secretion of the chancre. Daily rubs with 1 dram of unguentum hydrargyri for one week may cause the dark-field examination to become negative. It may be mentioned here that a single injection of arsphenamine usually causes spirochetes to disappear from the secretion of chancres within from six to eight hours. Infection of a chancre with pyogenic organisms may sometimes cause the spirochetes to disappear from the chancre, or reduce their number so that they can be demonstrated only with difficulty.

In previously treated chancres the serum from the deepest part of the sore should always be examined, as it is unlikely that spirochetes will be found near the surface. When the dark field is negative, the

* Supplementary to Chapter XX, Vol. I, p. 675, and Chapter XCIV, Vol. VI, p. 105.

application of alcohol to the surface of a chancre may be of service by dilating the lymphatics and so bringing spirochetes to the surface of the lesion. The shorter the period from the appearance of the chancre, the more likely it is that the dark-field examination will be positive; the longer the duration of the chancre, the more likely it is that its surface will heal, which makes impossible the dark-field examination. Furthermore, the possibility of a phimosis developing, which conceals the sore, is greater. The sore is also more likely to have had local treatment, and finally, pyogenic infection is more likely to be present.

Technic of Dark-field Examination.—The apparatus required for dark-field examination consists of an ordinary bacteriologic microscope with two accessories which are brought into use when required. The first of these is a special type of reflecting condenser which is fitted into the place occupied by the Abbé condenser. The second is a diaphragm, or stop, which is fitted to the back lens of the oil-immersion objective when this is used for dark-field work. Sometimes a special condenser is made to fit on the stage of the microscope and may then be used with or without the ordinary substage condenser, according to the pattern of reflecting condenser selected.

The illumination for a dark-field examination depends on the type of condenser. Direct sunlight may be used if artificial light is not available. A paraboloid type of condenser demands a strong illumination, such as an arc or Nernst lamp, though a good acetylene or a spirit vapor lamp can be made to serve if carefully adjusted. A hemispheric type of condenser will work with any of the above lamps, or with an inverted gas mantle, if this is properly arranged.

To demonstrate the Spirochæta pallida in the dark-field illumination the sore must first be cleansed to remove the surface spirochetes (Spirochæta refringens, Sp. calligyrum, and Treponema minutum). The serum is then made to ooze from the margin of the sore rather than from its ulcerated or eroded center. In order to obtain clear serum it may be necessary to briskly rub the surface of the sore; this procedure at first produces a flow of blood, later, however, clear serum is obtained. This serum is then transferred to a cover-slip either directly or by means of a platinum tip. The cover-slip is then placed on a glass slide of the proper thickness in such a manner that the fluid is between the cover-slip and the glass slide. Cedar oil is placed both on the cover-slip and the substage of the condenser. The specimen is then ready for examination with the oil-immersion lens after focusing and the proper arranging of the light. As observed under dark-ground illumination the Spirochæta pallida is a perfectly regular, closely twisted spiral, like a very fine spiral spring. Its coils are clean cut and appear dead white, not dazzling like those of other spirochetes. The movements of Spirochæta pallida are generally typical; its progress across the field is very slow, but it twists on its long axis and alternately expands and closes its coils. In flexibility it has no equal among other spirochetes; it may bend so that one-half is at right angles, or even an acute angle

with the other, or may form a few of its coils into a small loop, while keeping the rest of its body rigid. In length the Spirochæta pallida may be as short as 4 microns or as long as 24 microns, the average being 8 to 10 microns. The relation which the number of spirals bears to a given length is an important aid to the diagnosis. If a Spirochæta pallida and a neighboring blood-cell be compared, it will be seen that one can count seven coils of the spirochete to the width of the blood-cell.

Other spirochetes which may be found on genital sores can be differentiated from the pallida in the following manner: Spirochæta refringens is a very coarse spirochete with very few spirals to a given length, and it travels across the field very quickly. Spirochæta calligyrum (Noguchi), Spirochæta gracilis (Levaditi and Stanesco) is closely coiled and regular like pallida, and it is more flexible than Spirochæta refringens, so that it may be taken for pallida by the unwary. If they are compared side by side it will be seen that calligyrum is twice as thick as pallida. It is, moreover, not so flexible, moves faster over the field, and a comparison of the number of its coils to the diameter of a red blood-cell shows that there are only about five in this length of spirochete. The Treponema minutum (Noguchi) is a smaller organism than pallida, it is thinner, and it moves with considerably less rapidity than pallida.

The Spirochæta pallida is preferably detected by dark-field examination. However, it may be demonstrated by staining. The Leishmann, Burri, Fontana, or India-ink methods may be used. All these dried-film methods have the great disadvantage that they fail to demonstrate the movements of the Spirochæta pallida, which are of the greatest diagnostic value. More time is consumed in preparing the specimen, and, as a rule, it is necessary to search it more thoroughly before a Spirochæta pallida is found.

The Wassermann Reaction in Primary Syphilis.—The value of the Wassermann reaction as an aid to the early diagnosis of syphilis is in proportion to the duration of the chancre. At the time of the first appearance of the sore this reaction is invariably negative. The percentage of positive reactions gradually increases with the duration of the sore, until a short period before the appearance of the secondary eruption it becomes positive in 100 per cent. Therefore, in the early period of primary syphilis this reaction is not a very valuable diagnostic aid; in the later period, however, the reaction is of considerable diagnostic value. Within the first ten days of the appearance of the chancre the Wassermann reaction is positive in about 30 per cent. of cases. In from ten to twenty days after the appearance of the chancre it is positive in about 65 per cent. of cases. In from twenty to thirty days it is positive in about 75 per cent. of cases. In from thirty to forty days after the onset of the sore the Wassermann is positive in about 100 per cent. of cases; after forty days the reaction is usually positive in all cases.

A positive Wassermann means that a general invasion of the spirochetes has already taken place. The most favorable stage for the

successful treatment of syphilis is the pre-Wassermann period, *i. e.*, the period in which the Wassermann is still negative. The disease should be diagnosed and treatment instituted before spirochetic invasion occurs. The time of appearance of a positive Wassermann reaction in primary syphilis is variable. With the cholesterolized antigen, which is the most sensitive antigen used in the Wassermann reaction, exceptional cases may be positive in the first few days of the appearance of the chancre. On the other hand, the Wassermann reaction may not become positive until the appearance of the secondary eruption. This test should be carried out in primary syphilis with, however, an understanding of the above reservations.

The sooner the chancre is examined, the more likely it is that the dark-field examination will be positive and the less likely the Wassermann will be positive. Later, however, the converse is true. Therefore the dark-field examination is not only the preferable laboratory test, but it is also more successful than the Wassermann reaction in the diagnosis of early syphilis.

The Prophylaxis of Syphilis.—Mercurial ointments were used as a prophylaxis against syphilis before Metchnikoff and Roux[1] published their observations on the prevention of syphilis in apes by the use of calomel ointment. It was not until this time that the method came into general use. In 1906 these investigators reported that having tried twelve experiments on monkeys, with uniformly satisfactory results, they next performed the experiment on a man. The subject of this classical experiment was the younger Maisonneuve, who was then a student of medicine. He later published this experiment on himself as part of his thesis[2] for the doctorate. Maisonneuve was scarified on the left side of the balanopreputial fold with a scarificator charged with syphilitic virus obtained from a chancre. The right side of the balanopreputial fold was also inoculated in the same way with virus obtained from another chancre. The same virus was inoculated in a chimpanzee, which, however, died of pneumonia after ten days, and also into both eyebrows of four macacus monkeys. An hour after the inoculation the parts inoculated on the man and on one monkey were rubbed for fifteen minutes with the 30 per cent. calomel ointment. Twenty hours after the inoculation the eyebrows of the second monkey were rubbed with the same ointment. The other two monkeys were left as controls. The man did not develop syphilis, though watched for two months (he was previously regarded as a non-syphilitic, either acquired or hereditary). Seventeen days after the inoculation the two control monkeys that were not treated with the ointment both developed primary lesions, while the monkey treated after a twenty-hour interval developed a chancre after thirty-nine days' incubation.

Soon after these experiments of Metchnikoff and Roux there were reported cases in which the use of calomel ointment failed to protect. Levy-Bing[3] reported one of the first such cases, a patient of Gaucher's, in which exposure occurred May 19, 1906, and calomel ointment was used immediately after, but a chancre developed on June 13th, and on

July 17th the patient developed a generalized macular eruption. Levy-Bing concluded that inunctions with calomel ointment may not afford absolute security to those who use it even when it is applied during the first hours following exposure. It is obvious that these occasional failures in practice do not invalidate the experiments of Metchnikoff and Roux.

Calomel ointment as a prophylaxis against syphilis has been in use for a number of years in most armies throughout the world. From the many reports in the literature from these sources concerning its efficacy there is no doubt that the incidence of syphilis has been greatly decreased in these organizations. One of the best articles on this subject is by Riggs,[4] who recorded 5103 prophylactic treatments, with only 81 infections, as shown by the following table. The prophylactic used consisted of an injection of a silver salt of moderate strength and the use of 33 per cent. calomel ointment.

Hours subsequent to exposure.	Number of treatments.	Number of infections.	Percentage of infections.
1	1180	1	0.08
2	1172	7	0.59
3	521	4	0.77
4	330	2	0.61
5	199	3	1.57
6	321	5	1.58
7	277	6	2.27
8	390	16	4.22
9	283	10	3.62
10	214	11	5.14
More than 10	216	16	7.40
Total	5103	81	1.58

The above table emphasizes the importance of administering the prophylactic treatment within a few hours subsequent to exposure.

Metchnikoff's modified ointment was composed of 10 parts of calomel and 20 parts of lanolin. Although he found that an ointment to be effective must contain at least 25 per cent. of calomel, he recommended 33 per cent.

It is of sufficient importance to point out that because of its water content the calomel will be more active when prepared with official lanolin rather than anhydrous lanolin. It may be further pointed out that great care should be taken in the incorporation of the ingredients to insure thorough mixing. No doubt many failures of this agent in actual practice may be attributed to ignorance or negligence on the part of the pharmacist in not following these directions.

The following directions for use of venereal prophylaxis is taken from the Manual of the Medical Department of the United States Army:

DIRECTIONS FOR USE

1. Urinate.

2. Wash the genital organs thoroughly with soap and warm water, using a swab of absorbent cotton. Pull foreskin back and wash thoroughly behind head of penis and underneath along the frenum.

3. Wash thoroughly in the same manner with a 1 : 2000 bichlorid solution.

4. Fill urethra full of a 2 per cent. protargol solution (about 10 c.c. will be required for this). Retain three minutes by the clock.

5. Eject protargol solution from the urethra.

6. Rub the entire penis with the calomel ointment, care being taken that the folds of the prepuce about the frenum are thoroughly covered. If any pimples or abrasions exist about the scrotum or the pubic region, they should also receive an application of the ointment.

Vedder[5] formulates the following outline which he has found to be a satisfactory method of using prophylaxis:

"Before intercourse use a liberal amount of vaselin or other lubricant. This aids in preventing abrasions and forms a coating through which infectious organisms can only penetrate with difficulty.

" As soon as possible after intercourse:

"1. Wash the genitalia thoroughly with soap and water, using plenty of soap. Reasoner has found that soap solution kills Treponema pallidum very promptly, and there is good evidence that chancroidal infection may also be avoided very largely by a thorough cleansing with soap and water.

"2. When the prophylaxis is performed under medical instruction or by a man of sufficient intelligence this may be followed by a wash in 1 : 1000 mercuric chlorid. The efficacy of this solution is undoubted, but it should not be used by ignorant persons, nor should bichlorid of mercury tablets be issued as a routine.

"3. Dry, and apply about 1 dram of 33 per cent. calomel ointment in lanolin. Anhydrous lanolin should not be used and the ointment should be thoroughly mixed. This should be well rubbed in, paying particular attention to the glans, corona, and prepuce, but neglecting no part of the penis and the anterior portion of the scrotum. This should be rubbed in for at least ten minutes, and should not be removed, but should be allowed to remain for twelve hours, meanwhile protecting the clothes by the application of an impervious paper napkin. This favors absorption and ensures prolonged action of the mercury on any organisms that may remain.

"4. For the prevention of gonorrhea a suitable solution of some silver salt may be instilled into the urethra."

The status of calomel ointment as a prophylaxis against syphilis is well stated by Vedder:

"We may conclude that the experimental work on the prevention of syphilis and long experience with the practical use of a prophylactic have given substantially concordant results, namely, that syphilis undoubtedly can be prevented by the use of various prophylactics, and particularly by the use of 33 per cent. calomel ointment. In practice it cannot be expected that the use of the prophylactic will be invariably successful, but it seems reasonable to believe that if properly applied during the first hour after exposure it will prevent the great majority of syphilitic infections. The efficacy of the prophylactic diminishes

rapidly as the time between its use and the exposure increases. In addition to this time factor their will be variations in efficacy in practice, depending upon the care with which the calomel ointment is compounded and upon the intelligence and thoroughness with which it is applied."

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TREATMENT OF SYPHILIS

The treatment of syphilis was revolutionized in 1909 by the introduction of a group of new arsenicals by Ehrlich, of Frankfort, Germany. In September, 1909 Alt, of Uchtsprunge, received for clinical trial from Ehrlich an arsenical preparation which was called "dioxydiamino-arsenobenzol"; this had been prepared by Berthheim, a chemical associate on Ehrlich's staff. The preparation was first administered to dogs, and then two physicians tried it upon themselves.

The discovery of Ehrlich and his associates was not a sudden, accidental finding. It proceeded rather as a matter of course from a long series of carefully planned and logical researches along the lines of the new science of chemotherapy which Ehrlich was establishing. Ehrlich had some few years previously produced several polyazo dyestuffs, particularly "trypan-red" and "trypan-blue," which were capable of destroying trypanosomes in experimentally infected animals. Ehrlich ascribed much of the therapeutic activity of these substances to the presence of the "amino" and "hydroxyl" groups (NH_2 and OH). He then experimented with organic combinations of phosphorus, arsenic, and antimony. The compound known as "atoxyl," introduced by Bechamp, and known to possess certain definite therapeutic influence in syphilis, attracted his attention. He and Berthheim studied and revised the chemical formula of this substance. Atoxyl then became the starting-point of a long series of intensive and brilliant chemical and biologic experiments, culminating in the elaboration of "dioxydiamino-arsenobenzol," later marketed under the trade name of "salvarsan."

Dioxydiamino-arsenobenzol is a light yellow powder containing theoretically 34 per cent. of arsenic. As a matter of fact, owing to water of condensation and crystallization, etc., it rarely contains this amount. The United States Public Health Laboratories require that the drug shall contain between 29 and 31 per cent. of arsenic. The drug must, moreover, be free of inorganic arsenic.

The great stroke of genius in Ehrlich's work lay in introducing a substance (arsenic) which had a high affinity for the body cells and a

relatively low affinity for the parasite of syphilis into a molecule in which these relationships were reversed. The new compound has a strong chemical affinity for the spirochetes and a low combining power with the body tissues. In other words, the drug is strongly parasitotropic and but weakly organotropic. This adequately explains the reason why such large doses can be introduced directly into the bloodstream without bad effects. When 0.6 gm. of dioxydiamino-arsenobenzol are administrated we introduce between 2 and 3 grains of arsenic, but it is no longer arsenic as such. If, however, the compound should have become oxidized before injection, or the patient should, for one reason or another (later to be discussed), fail properly to eliminate the drug, arsenic poisoning might occur, and indeed, has taken place.

Designation of the Compound.—When the German Manufacturing Laboratories, to whom the patents were assigned by Ehrlich and Berthheim, had the exclusive monopoly of the drug it was proper to designate it "salvarsan." This word has become so closely identified with the chemical substance itself, and moreover, has infiltrated medical literature to such an extent that many physicians still employ it to mean the chemical compound.

By act of Congress in 1917 the President of the United States was empowered to license American citizens to manufacture and supply this drug. The Federal Board Commission, under expert advice, adopted the excellent word "arsphenamine" as the official designation for this substance. The term "salvarsan" should, therefore, no longer be used except where it is the purpose to refer to the brand or trade name of particular laboratories. Arsphenamine is now made in Philadelphia, New York, Buffalo, Toronto, London, Paris, Tokio, and other places under special brand names. The first American product was made in Philadelphia.

The most approved and almost universally employed method at the present time is by intravenous infusion. This method when properly performed is virtually painless, and can be repeated as often as is necessary.

Schamberg and Kolmer have tested out the use of the drug by mouth both in animals and man, but the curative effects are too feeble to warrant its employment by this method except in isolated instances. The drug has also been used by colonic instillation, but there again the effect is far inferior to intravenous injections. The same can be said of the use of the drug in suppositories.

Value of Arsphenamine in Syphilis.—The accumulated experience of the past ten years has definitely established the fact that this is the most remarkable synthetic chemical compound introduced into medicine, and is the premier remedy in the treatment of syphilis, yaws (frambesia), relapsing fever, and in certain other affections. To be sure, the initial hope of Ehrlich, that of a "therapia sterilisans magna," a cure at a stroke, has not been generally realized. In cases of early primary syphilis, and occasionally in other cases, such a cure after one or several injections at times takes place. In "yaws," a tropical infec-

tion allied to syphilis and caused by the Treponema pertenuis, cure after one injection takes place in a very high percentage of cases.

The number of treatments required in the treatment of syphilis varies enormously, and is, in a general way, in proportion to the age of the disease.

Arsphenamine has a great superiority over mercury. It has a greater affinity for the parasite and a lower affinity for the body cells. By reason of the latter it can be administered in far greater doses, a most important consideration in the intensive treatment of the disease. In the experimental animal it is about fifty times less toxic than mercury. Arsphenamine has, moreover, a tonic effect, improving the color and increasing the weight. Mercury in large doses is prone to produce pallor and loss of weight. The massive use of mercury is prone to injure the kidneys. It has a special affinity for the kidneys, a fact which is well exemplified in bichlorid of mercury poisoning.

Although arsphenamine is distinctly the remedy of choice, there is no adequate reason why we should discard such a well-tried and useful drug as mercury. The spirochete has an "arsenoreceptor" and a "mercuroreceptor." By the appropriate use of both remedies it is reasonable to believe that better results can be obtained in the long run than by the exclusive use of one or the other.

The effect of arsphenamine upon the obvious symptoms of the disease is often nothing short of magical. Lesions of the mucous membranes commonly heal up with astonishing rapidity in twenty-four or forty-eight hours. Spirochetes often disappear from chancres within six to eight hours. To be sure, these results, while theatrically impressive, are not sufficient criteria of the curative value of the drug. The reversal of serologic tests and the permanent eradication of the disease are the important standards. In many cases these results are achieved.

Mode of Administration of the Organic Arsenicals.—Arsphenamine ("606") was first employed by subcutaneous and intramuscular injection, but the great pain and necrosis which followed led to the abandonment of these methods. The almost universal route of administration at the present day is directly into the veins. Different forms of apparatus and diverse modes of procedure have been used from time to time, but the following technic is the one generally approved: After the ampule containing the drug has been filed open the contents of the same are dropped into a sterile glass mixing cylinder containing freshly distilled water; 20 c.c. of water are to be used for each decigram of the drug. The cylinder is agitated until complete solution takes place. Inasmuch as arsphenamine is dispensed as the hydrochlorid the solution is acid. Acid solutions are much more toxic than alkaline solutions and it is, therefore, necessary to neutralize the liquid before injection. For this purpose a 15 per cent. solution of chemically pure sodium hydrate is employed. It is desirable to keep the sodium hydrate solution in a vial made of Jena glass or some other non-soluble glass, in order to prevent the dissolving out of silicates, with ultimate precipitation. About two-thirds of the necessary amount of alkali

should be dropped into the solution quickly; for a dose of 0.6 gm. this would be in the neighborhood of 12 to 15 drops, depending, of course, upon the aperture of the pipet employed. As soon as the alkali comes in contact with the arsphenamine a white cloud forms, which later dissolves. Later a dense precipitate forms, which upon the further addition of alkali drop by drop is redissolved, resulting in a perfectly clear solution. The dense precipitate represents the neutral arsenobenzene base which is insoluble. The further addition of alkali produces the sodium salt which is soluble.

The Ehrlich method of neutralization required the addition of just sufficient alkali to clear the solution. French writers have in recent years called attention to the fact that this method of neutralization does not completely neutralize, but leads to the formation of the *monosodium salt*. They claimed that it was preferable to produce the *disodium salt*, which gives to the solution greater stability and renders the precipitation of the solution by the blood less likely. To produce the disodium salt it is necessary to add one-third more alkali than is necessary to clear the solution. It is claimed that fewer reactions occur after the use of the disodium salt. There can be no doubt that the disodium solution is more stabile than the monosodium, and that it is less likely to be precipitated, particularly when the two are compared in relatively concentrated solutions.

The temperature of the water employed to dissolve the arsphenamine should be about 20° to 30° C. With some brands of arsphenamine the use of extremely hot water may lead to oxidation of the drug, with an increase in the toxicity. At the time of injection the water should be between room and body temperature.

Several types of apparatus have been devised for the injections. The simplest is a graduated glass buret holding about 150 to 200 c.c., to which a rubber tubing is attached with a glass window near the end. The needle should be of 19 to 21 gage and possess a point which is neither too long, on the one hand, nor too blunt on the other. After a tourniquet has been applied above the elbow and the most prominent vein selected, the needle is inserted into the vein. The free and continuous flow of blood through the needle demonstrates that it is in the vein. The tubing is then attached and a few cubic centimeters of distilled water are allowed to flow in. If the line of the fluid in the buret declines and there is no pain or swelling, the arsphenamine solution is filtered into the buret through sterile cotton or gauze, and allowed to flow. Care should be taken that the infusion be not given too quickly, for it has been proved on animals that the rate of flow distinctly influcnces the toxicity of the drug. If it is desired to give all of the fluid in the tubing, this must be accomplished by the addition of distilled water as the buret becomes empty. Some physicians employ physiologic salt solution instead of water, but I do not see any advantage in so doing.

There has been a tendency on the part of some physicians to administer arsphenamine in *concentrated solution* in a piston syringe. I

know that hundreds of injections have been given in 30 c.c. of water, and, I have been informed, without untoward results. On the other hand, I know of several deaths and other severe reactions that have followed this procedure. A concentrated acid or unneutralized solution would almost surely induce a fatal result, and even alkaline solutions may under certain circumstances lead to disaster. The United States Public Health Laboratory has condemned the method and has indeed advocated 180 c.c. for each 0.6 gm. of the drug. For the present, at least, concentrated solutions of arsphenamine had best not be employed.

The **dose of arsphenamine** should be guided by the age, weight, and vigor of the patient, and likewise the stage of the disease and the frequency of administration. In the very early stages, where it is desirable to bring about an abortive cure, one is more justified in using large doses than late in the disease. It is obvious that a puny man of 110 or 120 pounds weight is not entitled to receive the same dose as a muscular giant of 180 or 200 pounds. One decigram of the drug for each 30 pounds is a fairly good general guide.

The **frequency of administration** of the drug obviously influences the dose to be administered. A weekly dose would naturally be larger than the dose given twice a week.

Contraindications.—With the exercise of good judgment as to dosage the contraindications are not as numerous or as compelling as formerly enunciated. The most important contraindication is severe disease of the kidneys. The drug is largely eliminated through the kidneys; if it is not freely eliminated it may be deposited in the liver and other organs and undergo oxidation, with the production of symptoms of arsenic poisoning, or it may irritate the damaged kidneys and lead to suppression. In severe myocarditis, too, the use of the drug is to be prohibited. In valvular disease of the heart with compensation small doses may be given without untoward results. I have administered small doses (0.3 mg.) to a patient with a large aneurysm of the arch of the aorta with subjective relief. In cases of gastric ulcer or in other conditions in which hemorrhage may readily occur the drug must be used with great care or not at all.

Types of Reaction.—There are various types of reaction that may develop after the administration of arsphenamine and neo-arsphenamine. Everyone is familiar with the *vasomotor reactions* which not infrequently manifest themselves before the intravenous infusion is completed or immediately thereafter.

The commonest initial symptom is flushing of the face, although an earlier symptom with some patients is a peculiar gustatory sensation, often of an ethereal character, the patient remarking that he can taste the drug. A burning sensation of the lips or tongue may be complained of. The flushing may be slight and transitory, or it may be pronounced, accompanied by injection of the conjunctiva, lacrimation, edema and swelling of the lips, tongue, or eyelids, an anxious expression of the countenance, cyanosis, nausea followed by retching and vomiting, and this, in turn, by profuse perspiration. In some cases cough, respiratory

embarrassment, and dyspnea are observed. The pulse at first is full and bounding, but later slow and of a very small volume, in which event it is usually accompanied by a death-like pallor. In severe cases the patient may lose consciousness and the pulse may be scarcely palpable at the wrist. In some cases epileptiform convulsions may take place, and the patients are known to have fallen off the table from the violence of the convulsive movements. In rare cases death has occurred, although most patients, even when apparently *in extremis*, will recover from the attack. Among uncommon symptoms observed during the stage is an urticarial eruption, and in other patients a severe pain in the lumbar region. The symptoms just described may disappear in fifteen minutes, being followed by considerable lassitude. As a rule, later reactive manifestations of a different character manifest themselves.

Febrile and Gastro-intestinal Reactive Manifestations.—These symptoms usually make their appearance about three hours after intravenous infusion of the arsenic solution. The patient commonly complains of one or several of the following symptoms: headache, chilliness, or active rigor with shivering, fever, nausea, vomiting, and diarrhea. These occur in varying grades of intensity. The patient may merely feel "queer," or there may be repeated chills, numerous attacks of emesis, and profuse and protracted diarrhea. Occasionally severe pains in the back and limbs are complained of. This complex of symptoms usually subsides in three to six hours and is followed by a feeling of lassitude or weakness. In rarer instances vomiting and diarrhea, associated with fever, may continue for a number of days, the patient being unable during this time to retain any nourishment. A patient under my care ran a temperature of 104° F. for three days following the administration of arsphenamine, but made a good recovery. In some instances the urine may be scanty and contain albumin and casts.

Certain **eruptions** have been observed to develop at times after the administration of arsphenamine, appearing in either a few hours or several days. These have been of an urticarial, scarlatinoid, or morbilliform character. In rare cases the eruption has been purpuric. I have in several instances observed a pruritus or itching of the skin unaccompanied by any eruption. Most of the eruptions are evanescent and disappear after a few hours' or days' duration. Later and more persistent and more serious eruptions have been observed to occur about six to ten days after the administration of the drug, more particularly when the drug has been given by the intramuscular route. Some instances of *universal exfoliative dermatitis* have been reported persisting for weeks, with fever and debility, and sometimes leading to a fatal termination.

A third group of **serious late reactions** comprise those which come on one or several days after the administration of the drug and which are characterized by alarming brain symptoms. In some cases there may be headache, vomiting, muscular twitchings, epileptiform con-

vulsions, dilatation of the pupils, absent reflexes, coma, and death. These cases are usually the expression of an edema of the brain or an encephalitis hæmorrhagica. Meirowsky and Kretzmer have shown that of 109 fatalities after salvarsan recorded in literature, 41 per cent. occurred in the secondary period and 29 per cent. in late nerve syphilis. Three-fifths of the fatalities during the secondary period resulted from encephalitis; 45 per cent. of these occurred in cases in which the dose exceeded 0.5 gram. The size of the dose and the frequency of the injections are alleged to bear a direct relationship to the incidence of encephalitis.

Another syndrome following the administration of arsphenamine is characterized by severe **jaundice**, accompanied, as a rule, by fever. This may appear in from three days to several weeks after treatment. Such accidents are more frequent after intramuscular than after intravenous injections. Most cases of postarsphenamine jaundice pursue a favorable course, but there are exceptional cases which terminate fatally, with the symptoms and autopsy findings of acute yellow atrophy of the liver.

The Causes of Arsphenamine Reactions.—The elucidation of the causes of reactions after arsphenamine has been involved in much obscurity. The factors operative in the causation of the febrile and gastro-intestinal symptoms have received much consideration in literature. Neisser believed that these symptoms were due to an endotoxemia resulting from the massive destruction of spirochetes by the drug and the liberation of the endotoxins from the dead parasites. That this factor is capable of inducing the symptoms referred to is probable, from the oft-confirmed observation that the first injection in a florid syphilis is more often followed by fever, vomiting, etc., than subsequent injections. But this is only one cause and does not explain the reactions which occur in primary syphilis and in latent syphilis when a massive destruction of spirochetes does not take place. Luitheln and Mucha have set forth the thesis that the febrile and gastro-intestinal symptoms are due to the absorption of broken-down cellular detritus resulting from the injection. This is an unproved hypothesis and, furthermore, fails to satisfactorily explain the phenomena referred to.

Wechselmann advanced the view that the type of reaction under discussion resulted from the use of impure water employed to dissolve the drug. He states that since the use of freshly distilled sterile water in his clinic the number of reactions had been enormously reduced. The water impurities were chiefly bacterial proteins, which might still be present even though the water was recently sterilized. This view was accepted and endorsed by Ehrlich, Max Müller, Yakimoff, and others. There can be no doubt that a foreign protein in solution is capable, when injected into the circulation, of inducing fever and other symptoms. Wechselmann was doubtless correct in assigning "impure water" as a cause of fever and gastro-intestinal reactions, but to regard it as *the* cause of such phenomena was to overstate the facts in the case. Other causes are more often operative in the production of these

symptoms. Emery, Gonder, Matzenauer, and Dreyfuss all entertained the view that the presence of certain inorganic impurities in the water employed, such as copper, lead, silicates, calcium, magnesium, etc., increased the toxicity of the solution of the drug. These doubtless play an uncommon and relatively unimportant part in the causation of reactions.

The Causes of Reactive Symptoms After Arsphenamine.—From what has just been stated it is evident that there is no one cause to be incriminated. There are many causes, but to assign to each its proper evaluation is a difficult task. Furthermore, there are certain syndromes which can, I think, be charged to different causative factors.

The causes of reactions may be considered under three headings: (1) Factors related to the patient; (2) factors related to the technic, and (3) factors related to the drug.

1. **Factors Related to the Patient.**—It is obvious to every practitioner of experience that personal susceptibility plays an important rôle in reactions. We have repeatedly administered arsphenamine to a number of patients at the same time and from the same receptacle, and have observed that some would have pronounced febrile and gastrointestinal reactions, whereas others, sometimes receiving higher dosage, would remain entirely free. My associate, Dr. Kolmer, has observed as a matter of common experience that rabbits receiving 60 mg. per kilo of body weight (equivalent to 4.2 gm. to 150 pounds) would exhibit marked variation in resisting power, one tolerating the drug and another succumbing to the same dose of the identical lot. The susceptibility to arsphenamine varies, therefore, both in man and in lower animals.

Human beings vary, too, in the functional and structural integrity of their organs, and this is notably true of patients with syphilis, in whom vascular changes take place so commonly. I believe, with Wechselmann, that a number of arsphemamine fatalities may be ascribed to renal insufficiency. I have known on several occasions a death to occur from the administration of the drug from one ampule of a given lot of arsphenamine, and yet the remaining 300 ampules of the same lot number to be well tolerated. Under such circumstances it is obvious that the condition of the subject was a factor in the outcome, although it need not necessarily be assumed that it was the sole and only factor.

Autopsies in cases of salvarsan fatalities abroad have discovered the presence of such conditions as acute tuberculosis of the brain, gastric ulcer, status thymolymphaticus, disease of the heart, liver, or kidney, etc.

I know of an instance that occurred in a hospital in Philadelphia, where a physician was about to administer arsphenamine before a class of students to a woman suffering from hepatic syphilis. A moment before the needle was inserted into the vein the patient suddenly expired. Had the death been delayed two minutes, nothing would have seemed more convincing than the death was due to the drug administered.

2. **Factors Related to the Technic.**—I have already referred to the

question of the purity of the water used as a solvent for the arsphenamine.

There are other faults of technic which may be responsible for reactive manifestations of varying grades of severity.

Schamberg and Raiziss have demonstrated that the use of the acid or unneutralized solutions of arsphenamine in ½ to 1 per cent. strength increases the toxicity of the drug in animals by 50 to 60 per cent. The toxicity of acid solutions is proportionate to the concentration. A full dose of 1 per cent. concentration—*i. e.*, 600 mg. in 60 c.c. of water—might well place the patient in jeopardy of his life. Whereas in 250 c.c. of water such an acid solution might be tolerated without reaction.

As regards the use of concentrated neutralized solutions there is some difference of opinion. Many physicians have expressed a preference for concentrated injections, and have claimed remarkable immunity as regards reactions. Our animal experiments bear out the statement that such concentration can be borne without evidence of increase of toxicity.

On the other hand, we believe that the best interests of patients in general will be subserved if the bulk of the solution of arsphenamine be not below 120 c.c. As I shall presently have occasion to say, traces of impurities commonly creep into arsphenamine despite the utmost precaution; a concentrated solution tends to exaggerate the influence of impurities because the drug is brought in more concentrated form in contact with the nerve centers.

There are other faults of technic which may be responsible for milder degrees of reaction, such as the use of too hot or too cold water, too acid or too alkaline solutions; the improper preparation of the patient for the treatment or improper after-treatment. The intravenous administration of the drug shortly after the eating of a meal, or the partaking of food too soon after the injection may induce gastro-intestinal symptoms. Physical overexertion before or directly after treatment may likewise be responsible for reactive phenomena. The use of unclean rubber tubing containing remains of an old oxidized arsphenamine has been known to give rise to severe reactions.

3. **Factors Related to the Medicament.**—In the interpretation of the causes of reactions following the use of arsphenamine too much attention has been paid to errors of technic and too little to causes related to the chemical compound itself. It may contain traces of various impurities each one of which may produce special phenomena in the patient. We have no right to regard arsphenamine (certainly as commercially offered) as a chemically pure substance. A standard of biologic purity can be adopted, however, which can be determined by animal testing, and the drug thus made safe. In producing arsphenamine on a large scale impurities may creep into the drug despite the utmost care, skill, and vigilance. It can be prepared in much greater purity in test-tubes and beakers than when it is manufactured on a commercial scale. While there are chemical tests to discover the presence of certain impurities, there are many impurities whose presence

cannot be determined by chemical means. Their nature is not known, owing to the extremely complicated character of the molecule.

It is a well-known fact that different lots of arsphenamine (and this is true of the original German product as well as that made in the United States and other countries) will commonly vary in their toxicity, *i. e.*, in the dose that will be tolerated by animals. Different lots may also vary as regards their oxidizability and within certain limits, as regards therapeutic effect. For, after all, therapeutic effect signifies toxicity for the parasite. Standards have very properly been established by the United States Public Health Laboratories which are designed to insure the safety of the drug as far as possible. All products released from American laboratories must pass the requirements adopted.

Causes of the Nitritoid Crises or Immediate Vasomotor Reactions.—These reactions have been variously interpreted as anaphylactoid phenomena, as due to precipitation of the drug in the blood (Danysz), and as due to some impurity in the drug (Schamberg, Raiziss, and Kolmer). The injection of a turbid solution of arsphenamine or neo-arsphenamine may, without question, induce sudden syncope and serious edema of the face or tongue. It is possible, therefore, that a precipitation of the arsphenamine in the blood due to insufficient alkalinization might induce similar symptoms, particularly when a concentrated solution is employed. It is a well-established clinical observation that certain lots of arsphenamine and neo-arsphenamine may produce nitritoid crises, whereas others produce practically none. It would appear, therefore, that something in the chemical or physicochemical constitution of the compound is at fault. It is possible that some change in the amino group may give rise to the vasoparetic substance. Future investigation will doubtless elucidate the cause or causes of these phenomena.

Unfortunately, with the enormous doses administered to animals they either live or die, but do not exhibit reactions such as are observed in man. Schamberg, Kolmer, and Raiziss are firmly of the opinion that the vasomotor or vasoparetic symptoms which occur during or immediately after administration of arsphenamine are due to the presence of an impurity or some other change in the drug. But this impurity or change cannot be determined by animal tests; animals do not flush or develop edema as human subjects do.

The substance or change, whatever its nature, appears to induce a paresis of the blood-vessels, characterized by marked dilatation and not infrequently by leakage of serum into the tissues.

There is a marked fall of blood-pressure with the vasoparetic symptoms, and in rare instances death may ensue. The prompt administration of 10 minims of a 1 : 1000 solution of adrenalin appears to exert a control over the severe symptoms.

The **febrile** and **gastro-intestinal reactions** are rarely followed by fatal accidents unless they are associated with evidence of severe nephritis. They are sufficiently disturbing to the patient to interfere with his physical well-being, and tend to make the patient fear the administration of the drug.

Mercurial Treatment.—Although early cases of syphilis may be cured by the intensive use of the organic arsenicals, surer results are obtained by the coincident or subsequent use of mercury.

Mercury may be used by inunction, by intravenous injection, by intramuscular injection, by inhalation, and by the mouth.

Inunctions.—The advantages of inunctions are efficiency and safety. A vigorous mercurial effect can be induced and the administration can be immediately interrupted if signs of mercurial intoxication develop. The disadvantages are that they are dirty, tell-tale, and sometimes occasion a dermatitis. The unguentum hydrargyri (50 per cent.) is the ointment usually employed; 4 grams (1 dram) of this should be rubbed into the skin nightly until thirty rubbings have been used. The flexor and non-hairy surfaces should be selected for anointing, the former to facilitate absorption, the latter to prevent folliculitis. One should rotate nightly, so that each area is rubbed but once a week. Much of the efficacy of inunctions depends upon the thoroughness with which the ointment is rubbed in. A slow firm pressure should be made with the palms.

It is contended by Prof. Welander, of Stockholm, and others that the vigorous rubbing tends to volatilize the mercury, and, indeed, that pulmonary absorption is the chief avenue of entrance of mercury into the body when the drug is applied to the skin. Certain experiments carried out by Schamberg, Raiziss, and Kolmer[1] indicate that the dominant channel of absorption is through the skin, but that some of the drug is volatilized and absorbed through the lungs. The wearing of a woolen shirt throughout the course of the rubbings is advantageous, as it becomes impregnated with the mercury, and gives off some mercury by volatilization from time to time.

Injections.—Although much research has been carried out within recent years to produce new organic mercury compounds superior to the old preparations in common use, these have not been attended with any signal success.

The soluble salts, such as the benzoate, the succinimid, the cyanid, and the bichlorid, are still regarded as the best of this class. The benzoate and bichlorid should be used in solution with sodium chlorid. The average dose of bichlorid and the cyanid is $\frac{1}{4}$ grain (0.015 gm.) intramuscularly in the buttock three times a week. The benzoate and succinimid can be given in $\frac{1}{3}$-grain (0.02 gm.) doses, as the mercury content of these salts is distinctly less. The soluble salts are active in their effect and safer than the insoluble, inasmuch as they do not lead to accumulation of the drug. The increased frequency of administration is, however, an inconvenience to most patients. Thirty injections given three times a week usually constitute a course.

Insoluble Injections.—Gray oil (metallic mercury), salicylate of mercury, and calomel are the three preparations ordinarily employed. Calomel is regarded as the most efficacious, but it is likewise the most painful. The dose is $\frac{1}{2}$ to 1 grain (0.03–0.06 gm.), and salicylate of mercury 1 to 2 grains (0.06–0.12 gm.) weekly. The salicylate contains considerably less mercury than calomel.

These compounds are usually dispensed in a 10 per cent. oil, such as the following:

℞. Hydrargyri salicylatis..... 10.0.
Petrolati liq..... 90.0.
Creosoti (beechwood)..... ♏ x.
Ten to fifteen minims to be injected.

The injections should be given high up in the gluteal region (about 2 inches below the crest of the ilium and in the outer quadrant). The needle should be first inserted. If no blood issues from the same, the syringe can be attached and the mercurial oil injected. If blood issues forth, the needle is in a vein and the injection of mercury would be apt to lead to pulmonary embolism.

The advantages of the insoluble injections are therapeutic efficiency and the convenience of weekly injections. The disadvantages are the liability to mercurial poisoning through accumulation of the drug if conservative dosage is overstepped, and the difficulty of overcoming the same if it develops. Painful nodulations are occasionally encountered and more rarely abscesses.

Intravenous Injections.—The bichlorid, succinimid, and the cyanid are at times used by intravenous injection. These bring about a rapid effect upon symptoms, but are inclined to sclerose and narrow the veins and render them unfit for subsequent intravenous medication. The cyanid of mercury in $\frac{1}{6}$-grain (0.01 gm.) doses daily was extensively used by the A. E. F. in France. The drug was given in 1 per cent. solution; the average dose was 1 c.c. It is said that if blood is first drawn into the syringe and mixed with the solution the veins do not become affected.

Inhalation.—The burning of certain pastils containing a high content of mercury incorporated in a dry vegetable mass appears to be an effective method of introducing mercury into the body. The pastil smolders and gives off fumes which the patient inhales under a sheet-tent. Mercurialization is brought about after five or six treatments. A convenient preparation of this character has recently been put upon the market.

When mercury is introduced into the body in vigorous dosage, particularly by injection or inhalation, it is essential to keep a close watch on the kidneys, as mercury has a special affinity for these organs.

Treatment by Mouth.—Although the oral administration of mercury is the feeblest and most uncertain method of introducing it into the body, decades of experience indicate that it has a measure of virtue. There are circumstances which arise which make it well nigh impossible for patients to take systematic treatment by the more vigorous and efficacious methods above referred to. Under such circumstances it is perfectly justifiable to administer mercury by mouth in the form of protoidid or biniodid pills, or any other of the older approved methods.

Iodin and the iodids have no direct destructive influence upon the parasite of syphilis. Nevertheless the iodids have a distinct place in the therapy of syphilis. In syphilitic fever, in the relief of bone-pains,

in nerve syphilis, and in late manifestations generally the iodids have a prompt therapeutic effect. The manner of the action of the iodids is still far from clear; that their action is an indirect one is highly probable.

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THE PRACTICAL MANAGEMENT OF SYPHILIS

There are three recognized drugs in the treatment of syphilis—arsphenamine, mercury, and the iodids.

Arsphenamine is generally recognized to be the remedy of paramount value. Its magical effect on symptoms is due to the fact that it has a powerfully destructive effect on the spirochetes and that it may be administered in large dosage. These two phenomena are due to the high parasitotropic influence of the drug and the low organotropic effect.

While there is unanimity of opinion as to the great value of intravenous infusions of arsphenamine, there is considerable divergence of sentiment as regards the dosage and the frequency of administration. Almost every syphilographer has his own therapeutic program for the treatment of syphilis. Some use arsphenamine alone, others combined with mercury. Some administer arsphenamine daily for several successive injections, some twice a week, some once weekly, and others at longer intervals. There is the same divergence of opinion as to the strength of the dosages. No plan has yet been suggested which commands the general acquiescence of the best medical opinion.

The custom of the largest body of physicians is to give one dose of 0.6 gram at weekly intervals. Pollitzer, of New York, one of the leading syphilographers of the country, has advocated a very intensive procedure consisting of three administrations of a full dose of arsphenamine on three successive days, with the idea of destroying the spirochetes by a sort of fractional sterilization; this series is to be repeated at proper intervals according to conditions. The principle underlying this treatment is sound, but, unfortunately, the extreme complexity of the manufacture of arsphenamine does not permit of absolute constancy in the drug. It is quite possible that improvements in the chemical processes employed may in time guarantee a product of uniformly low toxicity which will permit the more general adoption of the procedure in question.

The spirochete is vulnerable to arsphenamine and mercury. In an attempt to eradicate every spirochete as early in the disease as possible why should we not shoot two arrows? I realize that Wechselmann has warned against the use of mercury precedent to the use of arsphenamine, on the grounds that in his belief most of the arsphenamine fatalities are due in large part to renal insufficiency, and that in the majority of cases it was mercury that damaged the kidneys. There can be no doubt that mercury has a strong affinity for the renal cells. We are all familiar with the dominant symptoms in bichlorid of mercury

poisoning. Schamberg, Kolmer, and Raiziss have demonstrated in experimental animals the noxious influence of large doses of soluble and insoluble mercurial preparations on the kidneys. I believe that there is a considerable element of truth in the assertion that renal insufficiency is commonly a factor in contributing to or in actually causing deaths after the administration of arsphenamine.

My belief is that the use of three inunctions of mercury per week is a safe and valuable measure to associate with the use of arsphenamine, particularly in the primary and secondary stages of syphilis, at which time rapid sterilization is aimed at. The arsphenamine may be administered in 0.4- to 0.6-gram doses (depending on sex and body weight) once a week, or preferably in 0.3- to 0.4-gram doses twice a week. I believe the conjoint use of arsphenamine and mercury in moderate dosage is safer than the employment of either one singly in intensive dosage. The twice-a-week use of arsphenamine has the disadvantage of causing an increased inconvenience to the patient and of augmenting the expense of treatment, but in the manner suggested I believe that it combines safety and efficiency better than other methods.

No one is in an authoritative position today to state how long the treatment should continue. Too often the physician will cease treatment after a single series of arsphenamine injections and perhaps a course of mercury, because the Wassermann reaction has become negative. Experience proves that such a procedure requires the later resumption of treatment with valuable time lost. While it is difficult to prescribe any routine formula, we may at least indicate an irreducible minimum of treatment.

A patient with any early chancre and a negative Wassermann reaction should receive at least two series of arsphenamine administrations each consisting of six intravenous injections, and two courses of mercurial inunctions, each consisting of thirty rubbings. The likelihood of abortive cure with such a treatment is good.

Primary syphilis with positive Wassermann reaction or secondary syphilis will commonly require considerably more treatment during the first year. Treatment should be continued during the second year with somewhat decreased intensity, and during the third year with a diminishing number of treatments. If the Wassermann reaction remains positive, the treatment must be continued with such modifications as may be indicated by spinal fluid findings. We have had patients whose persistently positive Wassermann reactions were rendered negative by intraspinal medication, where such treatment was indicated by pathologic spinal fluid findings.

The weakness of the Wassermann test is on its negative side. We have all seen patients, from time to time, with negative blood tests and active syphilitic lesions present. We must bear this in mind and not be guided in the treatment by the serologic findings. When the Wassermann is positive, further treatment is indicated; when it is negative we should not cease our therapeutic endeavors unless the patient has had an adequate treatment. In our efforts to eradicate the infection we

should not, however, forget that the patient is to be treated as well as the disease. Loss of weight, strength, and vigor under intensive treatment should lead us to suspend specific treatment for a time and build up the patient's condition by proper tonic and hygienic measures.

The spinal fluid exhibits pathologic findings in a considerable percentage of cases of syphilis in the secondary period, or even, indeed, before this. That these changes represent an infection with the spirochete is demonstrated by the fact that inoculation of the fluid into the testicles of rabbits has resulted in the production of syphilomata. Most patients with syphilis escape ultimate involvement because of the action of local antibodies which destroy the spirochetes. Apart from this, early and adequate treatment is the most important safeguard. Most of the cases of tabes and paresis which have come under my personal observation have had little or no early treatment. I realize that many cases, however, that have had fairly vigorous early mercurial treatment have occurred in the past.

We know from years of experience that mercury and the iodids have proved helpful in the treatment of tabes dorsalis. The intravenous administration of arsphenamine is unquestionably of greater value in controlling the symptoms and arresting the disease. Of still greater value is the intraspinal treatment either by the Swift-Ellis, Ogilvie, or combined methods.

When cases of neurosyphilis fail to respond to intravenous injections of arsphenamine and to mercury and iodids, it is then good practice to resort to intraspinal therapy.

Intraspinal Therapy.—Swift-Ellis Method.—An intravenous injection of arsphenamine is given and about one-half hour later 20 c.c. of blood is withdrawn under sterile conditions, twice centrifuged to secure a clear serum, and is then heated to 56° C. for forty-five minutes, and injected later in the day into the spinal subdural space, after a preliminary withdrawal of an equal amount of spinal fluid, or the blood can be placed on ice over night and prepared and injected on the following day.

Ogilvie Method.—This procedure omits the preliminary intravenous injection, and substitutes the addition *in vitro* of a small quantity of arsphenamine, which is then injected into the spinal canal. The primary dose should never exceed $\frac{1}{4}$ milligram and should sometimes be less. In some cases this can be increased to $\frac{1}{2}$ milligram. The serum before the administration is heated, as in the Swift-Ellis method.

The most favored technic of intraspinal treatment combines these two methods, *i. e.*, giving a preliminary intravenous infusion and subsequently adding arsphenamine *in vitro*. The frequency of the treatments depends upon the type of neurosyphilis under treatment and the manner in which the injections are tolerated. On an average, treatments are given each fortnight for four to six administrations, and then a rest period given. The ultimate guide is the condition of the patient and of the spinal fluid as regards cell count, protein, gold test, and Wassermann reaction.

Byrnes has recommended the use of a mercurialized serum intraspinally. After a week of inunctions the blood is drawn off and centrifuged, and to this is added 1 c.c. of a solution containing $\frac{1}{50}$ grain of mercuric chlorid, which is then heated for half an hour at 56° C.

Some writers have reported good results in neurosyphilis from a spinal puncture with withdrawal of considerable fluid immediately before or immediately after an intravenous injection of arsphenamine.

Intraspinal treatment in many cases has accomplished results which were not obtained prior to this treatment by other methods.

Intraventricular Injections.—Within the past few years an attempt has been made in paresis to secure more efficient results by injecting serum into the lateral ventricle through a trephine opening in the skull. A number of physicians have employed this method, but up to the present time there is no convincing evidence that the results are superior to those obtained by the spinal treatment.

It is obvious that one cannot restore degenerated cells or tracts. The successful treatment of paresis and tabes should be instituted before distinct clinical symptoms are observable. The treatment of paresis, like the treatment of small-pox, should be a preventive one. In order that this may be accomplished the potential paretic must be recognized by his spinal fluid findings. Long before clinical evidence is at hand the colloidal gold test will give warning. If this is heeded and appropriate treatment instituted, paresis may be prevented.

Before any patient with syphilis is discharged from observation a diagnostic spinal puncture should be made.

CHANCROID

Chancroid, or "soft chancre," is a local contagious ulcer usually seen on the genitalia, but may occur elsewhere. It is inflammatory in nature and in some instances very destructive in its course. The usual incubation period is about three days. Ducrey[1] in 1889 described an organism which bears his name, and is generally conceded to be the etiologic factor.

The organism stains well with most stains, but particularly with carbol fuchsin, polychrome methylene-blue, and pyronin in Unna's carbol-pyronin-methyl-green mixture. It is Gram-negative. The organism is demonstrated with difficulty in the secretion from an old chancroid, but is more readily found in the pus from the depths or the wall of a chancroid of short duration.

Chancroid begins as a superficial ulcer, which later becomes deep, or as a pustule, which breaks down and forms an ulcer. The pustule, when appearing upon the mucous membrane, first appears as a minute yellow spot surrounded by an area of redness which gradually shades off into the surrounding tissue. If unruptured, the yellow central area grows larger and forms a conical-shaped pustule. Upon the integument the yellow area is likewise surrounded by a halo of inflammation. The resulting pustule soon breaks down and forms an ulcer. Such ulcers have gnawed, undermined edges. The floor has a dirty gray color and

is pitted and worm-eaten in appearance. An area of inflammation always surrounds the ulcer. Later the contour becomes irregular because while some parts of the ulcer tend to heal, others invade the normal tissue.

Chancroids are painful, bleed easily, and do not secrete serum as plentifully as do chancres. They are usually multiple, but may be single. Induration is usually absent.

Clinical Types of Chancroid.—Chancroids are seen in four clinical varieties:

1. **Ulcus molle,** the common type of ulcer which is punched out in appearance and has undermined edges.

2. **Ulcus molle miliaire** (follicular or acneform chancroid) begins as a small papule with a flat summit and sloping sides.

3. **Ulcus molle elevatum,** a flat sore raised above the surface of the skin.

4. **Ulcus molle serpiginosum** is a very chronic and destructive ulcer which usually has its beginning in a chancroid bubo. The ulcer shows a marked tendency to progressive irregular extension over the abdomen and the thighs, destroying more or less of the whole thickness of the skin. McDonagh[2] has demonstrated the Ducrey bacillus in the walls of an ulcer of this type. This ulcer, which is rarely seen in America, occurs chiefly in the tropics. It is very rebellious to treatment.

Ulcus Molle Phagedænicum.—Although this lesion is usually given as a variety of chancroid, it is, in reality, a complication. This complication is said to be caused by a symbiosis of a vibrio with Spirochæta balanitidis (Corbus and Harris[3]), although it has not been definitely established that the Spirochæta balanitidis has a more intimate relation to the lesion than that of a mere secondary invader (Noguchi[4]). This complication occurs as a markedly destructive ulceration which rapidly becomes gangrenous.

It is important to note that on clinical grounds alone the diagnosis of a chancroid is sometimes difficult to make. The truth of this becomes apparent when one considers that a pyogenically infected chancre, infected herpes, and genital ulcers due to other pyogenic organisms may simulate in clinical appearance a chancroid. Simultaneously with the inoculation of syphilis, infection with a chancroid or pyogenic organism may occur. Such a dual infection is generally known as mixed infection. It is by reason of the possibility of mixed infection that every genital sore is potentially syphilitic.

Treatment.—Until the diagnosis of a genital lesion is made absolutely certain no spirocheticidal drug should be applied. When the presence of syphilis is ruled out and the ulcer is proved to be chancroidal in nature, one or the other following methods of treatment may be employed:

The most rigid attention to cleanliness and to keeping the parts very dry are necessary in the treatment of chancroid.

Destructive cauterization is indicated for chancroid in the early stage and before the ulcers become complicated by much edema. The

frequently used silver nitrate stick as a caustic agent is not to be recommended. This drug irritates rather than destroys, and it is likely to produce considerable inflammatory edema. Cauterization by means of zinc ionization quickly causes chancroids to heal, but the use of this method is not practicable because of the special apparatus required and the time consumed in its application.

Of the powders, iodoform and calomel are often efficient, but the use of iodoform powder is frequently objectionable to the patient. Mills[5] reports good results from the application of sublimed sulphur. A great virtue of the sulphur treatment is the fact that this drug is not spirocheticidal, and therefore does not interfere with the finding of Spirochæta pallida if perchance the sore is syphilitic. Argyrol crystals applied directly to the sore for three or four minutes, followed by moist dressing of 10 per cent. argyrol or 1 per cent. protargol, have proved successful in some cases.

The application of concentrated solution of potassium permanganate, tincture of iodin, or a wet dressing of 2 per cent. dichloramin-T solution is frequently efficacious in healing the ulcers. The therapeutic use of the *x*-ray has given good results. The use of a mixed staphylococcus vaccine may prove of benefit.

The following treatment advocated by Robbins and Senbury[6] has given brilliant results: A 25 per cent. solution of copper sulphate in distilled water is applied to the sore after thorough cleaning of the surface, and the short high-frequency spark from a rather fine-pointed vacuum electrode is applied directly to the sore for from one to three minutes. During the treatment the elcctrode is held just over the sore, but should not touch it, as moisture from the sore will crack the electrode. The current is not turned off until every crack and surface has been thoroughly treated and the surface of the sore has assumed a dark greenish color. The application should extend beyond the edge of the sore into the doubtfully healthy area. After the treatment the surface of the sore is wiped dry and some antiseptic powder is applied to the entire lining of the preputial cavity. If the sore is exposed, it should be covered with a thick moist dressing of any very dilute antiseptic solution.

About forty-eight hours after the above treatment the treated areas present a healthy granulation that will go on to complete healing in a few days. The original cauterization may be repeated at any time when it is suspected that the chancroidal infection is not completely eliminated.

For the treatment of ulcus molle serpiginosum McDonagh advocates the internal administration of potassium iodid, cauterization by means of zinc ionization, the local application of camphophenol and iodoform, and the intravenous injection of tartar emetic.

The treatment of so-called phagedenic chancroid with anaërobic organisms consists in the use of hydrogen peroxid. If the sore is concealed beneath a tight or adherent foreskin, it is imperative to make a dorsal slit in order to expose the sore to the air.

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CHAPTER VI

GAS GANGRENE*

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This disease, known by the name of acute spreading traumatic emphysematous gangrene, was comparatively rare before the war. Owing to the researches of Welch one of the organisms responsible for the malady was known to be B. aërogenes capsulatus; other organisms were, however, suspected of being the cause of a similar disease. Five years has added much to our knowledge of the disease, but the very increase of knowledge has in many respects made the problem more difficult. The war came to an end at the very moment when the organization for the investigation of this disease seemed at last to promise a settlement of many of the problems. In no previous campaign has the disease figured to the extent it did in the war of 1914–18, even if it occurred at all. In the late war, under the name of gas gangrene, it quickly assumed a position of tragic importance. In the early period everything, as we now know, was in its favor. In the retreat to the Marne there was no possibility of early surgery—in fact, there were no Casualty Clearing Stations (hereafter called "C. C. S."). The ambulance trains were defective, evacuation difficult, and the journey to the base long. Even when the line became stabilized there was comparatively little early treatment of the majority of wounds until the spring of 1915.

The first improvement came about from an observation at the base that the disease was much less common in those wounds that had been drained at the front. The pathology was still but little understood, and treatment both at the base and at the front was confined to drainage, incisions, and amputations.

Even when drainage became the established practice at the C. C. S. the surgeon was still handicapped. In active times, when the numbers of wounded compelled rapid evacuation to the C. C. S., the numbers themselves prevented adequate surgical treatment. In quiet times the method of evacuation by convoy from the Field Ambulance to the C. C. S., which took place only once in twenty-four hours, caused the cases to arrive late. When once the operative treatment was commenced there was a continued fall in the incidence of the disease; and a further improvement followed when the systematic excision of muscle, which started in the autumn of 1915, became an established practice. Whenever circumstances compelled a return to early war conditions, and treatment was perforce transferred to the base, the number of cases

* Compare also the chapter on The Muscles, by J. F. Binnie, in Vol. VIII.

of the disease again increased, showing the effect of early operations in cutting short the disease. The experience of No. 7 General Hospital, St. Omer, may be quoted in this connection. This hospital received all the more severely wounded that passed through the C. C. S. in the Merville and Bethune areas. It was established in June, 1916, and during the many months in which it continued in active work gas gangrene was practically unknown. This does not mean, of course, that cases of gas gangrene did not occur in the C. C. S., but only that those cases which were quickly and adequately treated and in which the fulminating form of the disease did not appear, either avoided or were cured of the disease.

The conditions which determine the incidence of the disease have always remained more or less a mystery. It was more frequent in certain sectors than in others, but even in individual sectors the amount of the disease varied in different attacks which in their circumstances differed but little from one another. It was worse in cold weather, especially when the ground was wet. This possibly was connected with the more frequent occurrence of shock. The wounded arriving at the end of an attack were always more likely to be attacked than those collected early. On the other hand, it was a remarkable fact that many soldiers who had lain out in shell holes for days with bad wounds were found free from the disease when collected. This, however, was most probably a case of the survival of the fittest. An increase in gas gangrene was noted in attacks in wooded country or where the fighting swayed backward and forward, for here the collection was again extremely difficult. In the final advance over the devastated Somme battlefield the disease is said to have diminished, and this has been attributed to the fact that the battlefield had been unmanured and exposed to the sun and air for many months. At the same time it must be remembered that in this fighting the collection of the wounded was rapid, the number of shell injuries comparatively few, the weather favorable, and the operative facilities at the C. C. S. good. In the northern portion of the advance, namely, south of Arras, the percentage of gas gangrene cases was not materially different from that pertaining in some of the fighting in June, which took place north of Bethune and in an area where the soil had recently been tilled.

It is extremely difficult to give any reliable figures as to the frequency of the disease. Most probably the only figures which are reliable were those taken in the summer of 1918 when the serum treatment was being tried. In 1915 some statistics were collected in the Bethune area. These figures showed a percentage of about 5 per cent. in a particular C. C. S. Other figures collected from French and German sources put the percentage between 2 and 13, the latter figure being from a French source. The figures already referred to as being taken in the summer of 1918 can be trusted, for they were carefully observed and were of sufficient magnitude to eliminate error. They referred to parts of the line north of Bethune and show a percentage of rather over 1 per cent. among the wounded arriving at a C. C. S. (See page 94.)

Organisms Concerned in the Disease.*—These organisms are fecal in origin and are found in heavily manured soils. There is still a good deal of uncertainty about the number and nature of the individual organisms that were responsible for gas gangrene in the late war. The B. welchii, Vibrion septique, and the B. œdematiens may, with some certainty, be said to have been the principal agents and capable of causing the disease by themselves. The B. sporogenes, though incapable of producing the disease by itself, has played an important secondary rôle, mostly in association with the B. welchii. All four organisms are capable of breaking down carbohydrates and proteins and of producing hydrogen and carbonic dioxid in greater or less quantities. The B. welchii is the greatest gas producer, while the B. sporogenes, through the production of sulphids, was most probably responsible for the sickening odor of the wounds. The frequency with which these different bacilli appeared varied according to different observers. The B. welchii took the first place; next came the sporogenes, followed by the Vibrion septique and the B. œdematiens.

The anaërobic bacilli, almost universally present in wounds soon after receipt, if they do not gain an actual footing in the body, tend to die out and be replaced by the pus-producing organisms. At the same time they appear to be capable of lying dormant for long periods and, under certain circumstances not quite understood, of again becoming active.

Methods of Inoculation.—The soil containing the bacilli was directly implanted in the wounds or carried in by fragments of shells that burst after burying themselves in the ground. The clothes of the soldier—and to a less extent his skin—were always contaminated with dust and mud. Bullets, and especially shell fragments, therefore, that had touched no object since leaving the muzzle could easily implant the organisms. Pieces of clothing carried in by shell fragments were responsible for a very large number of the cases, the lacerated tissues produced by the shell fragments offering a favorable pabulum for the bacilli contained in the clothing.

Nature of the Disease.—Before the war and in the early part of the war the disease was looked upon as a general infection of the limb, the terms "gaseous cellulitis" and "massive gangrene" reflecting the ordinary views. While the bacilli were found present in nearly all wounds, it was recognized that they did not necessarily gain a footing in the body or produce more than local signs. In certain places, namely, the muscles, the cellular tissue, pleural blood, hematomata, and brain, it appeared they could live and flourish in varying degree, while the peritoneum and the cavity of joints (though the latter might contain gas) were practically immune. Comparatively early Sacquépée, the French pathologist, and Kenneth Taylor, an American pathologist working with the French, advanced the view that the disease was, in the main, an affection of the muscles. This view was later supported by Dunn, Frankau, McNee, and Wallace of the British service, who

* Compare Beebe's chapter on The Bacteriology of War Wounds.

pointed out that the disease hardly ever occurred or was but little to be feared except in the case of wounded muscles, and of tissues infiltrated with blood. It certainly appeared that the disease in most cases could be cut short by the excision of the muscles, though this treatment failed and has failed to the end to arrest the so-called fulminating cases. The muscle infection view of the disease has not been accepted by all, and doubt has again recently been thrown upon it by the laboratory workers in England, who maintain that the disease can be as easily produced in animals by injection of cultures into the subcutaneous tissue as into the muscles.

Accessory Causes.—Clinical observation has clearly shown that a defective blood-supply is the principal cause of the organisms gaining a footing in the body when they have once been introduced into wounds. A defective blood-supply may be caused in many ways. Death of the tissue may be produced by the blow of the projectile, or by the occlusion of vessels brought about either by actual severance or thrombosis following contusion. Among other causes may be included inefficient splinting which leads to injury of vessels or tissue, constriction of the limb by tourniquets, bandages, or badly applied splints, damming back of discharges by packing introduced into the wound, or by dressings in which the discharges have been allowed to dry and cake.

Hemorrhage, cold, and shock, by producing a low blood-pressure, were also potent factors. In the latter part of the war it came to be recognized more and more distinctly that a low blood-pressure was extremely dangerous and that the period of resuscitation must be shortened as much as possible.

It is very certain that the cutting off of the blood-supply to a muscle was a very important factor in its infection.

Some work done by Campbell and Pennefather is interesting in this connection. These observers studied the blood-supply of muscles by means of radiograms taken after injection of bismuth into their arterial supply.

Certain muscles, such as the gracilis, are dependent on one artery for their nourishment, others, especially the segmental muscles, have two or more arterial supplies (Bashford). Further observation showed that the circulation within a muscle is largely terminal, and that while the capillaries anastomose, the larger trunks do not. The severance or thrombosis of the artery in the case of a muscle with a single blood-supply will render that muscle bloodless. In the case of a muscle with several blood-supplies the severance or thrombosis of an artery, while it will not kill the entire muscle, will lead to the death of its own particular distribution.

These observations seem to offer an easy explanation of some well-known clinical facts:

(1) That a dead or gangrenous muscle may be found in the midst of a healthy group.

(2) The arrest of the disease at one point in a muscle.

(3) The subsequent death and infection of a muscle that was

healthy at the time of the primary cleaning operation. Here it would appear that the surgeon in performing the cleaning operation had inadvertently interfered with the blood-supply.

Gross Morbid Anatomy.—This can best be studied under two heads: (A) Group gangrene, and (B) segmental gangrene (massive).

These varieties are not really entities, but the division is convenient from a descriptive point of view.

(A) Group gangrene—here the gangrene is limited to a single muscle group; this can be further subdivided into: (1) A wounded muscle or muscle group from which the blood-supply has been cut off. (2) Infection of a wounded muscle or muscles with an intact blood-supply.

(A, 1) If, in such a case, the limb be dissected, it will be seen that a certain muscle or muscle group is dead, but in other respects but little altered except where wounded. Next to the dead muscles lie perfectly normal contractile muscles.

The disease, so to speak, is a longitudinal one; infection finds difficulty in passing from one muscle to another, but easily extends up and down a muscle from end to end. Next, the muscle involved changes in color, usually becoming brick red. This has been called the stage of red death. About this time the gas generated in the muscle becomes obvious to the eye as bubbles, which can be pressed up and down between the fibers. The substance of the muscles becomes friable; the color then changes to yellow, and possibly in the end becomes black and diffluent. The connective tissue lying in immediate contact with the diseased muscles may be little altered. At other times it is filled with white, yellow, or blood-stained edema. Gas may or may not be present in the areolar tissue, and when it is present tends to find its way along the main vessels of the limb. It also escapes into the subcutaneous tissues following the perforating arteries and often extends far beyond the limits of the disease.

(A, 2) **The Infection of Wounded Muscle or Muscles with an Intact Blood-supply.**—This is a comparatively rare phenomenon, living muscles showing very great resistance to invasion. Were this not so, the disease would be even more to be feared than it is. Ordinarily wounds are only contaminated with the bacilli which live in the muscle killed by the projectile. When actual infection takes place the spread of the disease can be seen as follows: The surface of the actual wound is dry or dirty looking, or in some cases black. Next to this is a red area, which is limited toward the sound tissue by a yellow sinuous line. This line is raised and hard to the touch; next to it lies the normal contractile muscle. The microscopic appearance will be described later on. (See Method of Extension.)

(B) **Segmental or Massive Gangrene.**—Here all or nearly all the muscles of a segment of a limb distal to a complete arterial lesion, deprived of their blood-supply, die and become infected. The appearances are similar to those seen in (A, 1) except that the muscles may not be wounded. The color of the muscle will depend on the degree to

which infection has passed, and the amount of gas and edema will vary in like manner.

Naked Eye Appearances Produced by the Different Bacteria.—It has been said in a previous paragraph that three organisms are mainly responsible for this disease. In animal experiments these three organisms produce somewhat different appearances (Muriel Robertson). Unfortunately, in man, owing to the difficulty of identifying the bacilli, there is difficulty in determining the appearance peculiar to each variety of infection. But from a study of the disease in man and experiments on animals the following would appear to be the naked eye changes produced by the infecting agents:

1. Bacillus welchii.

(*a*) Yellow edema, sometimes blood stained. (*b*) Large gas production. (*c*) A dull, dirty, brick red color of the muscles. (*d*) Soft pulpy muscles. (*e*) Slight sourish smell.

2. Vibrion septique.

(*a*) Blood-stained edema. (*b*) Considerable gas production. (*c*) Deep red color of the affected muscles. (*d*) An odor which is not putrid, but rather rancid in character.

3. Bacillus œdematiens.

(*a*) Colorless gelatinous edema. (*b*) A small amount of gas production. (*c*) Pale pink color of muscles.

4. Bacillus sporogenes.

(*a*) Olive green color of the muscles, the color turning to black. (*b*) A putrid odor.

Method of Extension.—Since nearly all wounds are contaminated, the question may be asked why the disease progresses in some cases and not in others; why it returns after amputation, and why in certain cases treatment fails to arrest the disease?

There is no proper answer to these questions. These differences may depend upon the different infecting agencies, but no precise information is available on the subject.

The advance in most cases is a local one, spreading centrifugally, while metastases may occur in certain places, such as the sites of hypodermic or saline injections, in the buttocks, which are subject to pressure, and in a few cases shortly before death in an unwounded limb. The blood-stream is not usually infected in the case of the B. welchii, though this happens more frequently in the case of the Vibrion septique.

Everything seems to point to the fact that a death of the tissue is a necessary antecedent to the spread of the bacteria. Consequently, there is no difficulty in understanding the spread of the infection in a muscle already deprived of its blood-supply. The question is, What kills the tissues when the blood-supply is intact?

Recent experiments have shown that the presence of calcium salts is an important factor in enabling the bacilli to gain a footing. Calcium is present in the soil with which the wounds were contaminated.

Taylor advanced the view that the gas produces the death of the tissues by its disruptive effects, but probably it only plays a secondary

part by producing a tension in the limb which interferes with the blood-supply.

d'Este Emery has shown how the toxin repels the leukocytes; indeed, the absence of any reaction is one of the most striking phenomena of the advance of the gangrene. This observation, however, seems to explain better the failure of nature to arrest the disease than to offer an explanation of how the living tissues are killed so as to afford a pabulum for the bacteria.

None of the above facts seem to offer an adequate explanation of the destruction of living tissue. The key to the problem probably lies in the observation that bacteria washed free of toxin are comparatively harmless.

To advance, the bacteria must elaborate a toxin which either kills the tissues by direct action or, as put forward by Bashford, by producing a thrombosis in the vessels by its action on the endothelial lining.

This suggestion is borne out by the work of McNee and Dunn on the microscopy of the advancing edge.

The following account is in their own words:

"The material examined histologically was almost always embedded in paraffin, after fixation in 10 per cent. formalin or in corrosive sublimate; frozen sections and tissue fixed by boiling were also used for the investigation of certain important points. Muscle taken for examination must be handled with great care or fallacies from artificial separation of the fibers may arise. The histology of single muscles, removed at operation and necessarily pulled on in the act, required, therefore, careful consideration before conclusions could be drawn from the sections. The best material was obtained from amputated limbs, in which the individual muscles could be carefully dissected and pieces cut out with a sharp knife or razor, all pulling being avoided.

"In a few cases only we have had the good fortune to obtain muscle with fairly long fibers, in which the advancing edge of a spreading gas gangrene could be clearly recognized. It is from these fortunate instances, however, by the examination of serial sections, that most of the information has been obtained of the method of spread. Macroscopically the appearance of this spreading margin is interesting. It is sometimes fairly sharp, but in other instances is irregular, from the process having spread further along some fibers than others. The muscle-fibers at the margin are paler and duller than the normal, but the color change is little more than might be accounted for by total loss of blood in the part involved. The outer limit of the process, while indefinite, can be mapped out fairly closely if the healthy muscle beyond is still contractile (in tissues examined very soon after amputation), contractility is lost in the part becoming gangrenous. At the advancing edge also the muscle tissue is very much firmer to touch than the healthy fibers beyond, and this firmness passes back into the obviously gangrenous muscle behind.

"When the whole of the advancing edge is cut out, along with a margin of tissue on either side of it, and examined in serial transverse

sections, the appearances presented are very striking, and are shown in the first three microscopic drawings (Plate I, and Plate II, Fig. 1).

"Plate I, Fig. 1 represents the muscle in transverse section just beyond the furthest limit of the advancing gangrene; the muscle here was still healthy and contractile. The muscle-fibers appear normal, and are seen to be made up of fibrils which show as dots in the transverse sections. The cracks in the fibers are artefacts produced in the cutting of the paraffin sections. They occur so constantly in transverse sections of normal fibers that they can almost be taken as characteristic of healthy muscle. The flattened nuclei of the sarcolemma are well seen, and also the interstitial tissue between the fibers, which carries the blood-vessels, lymphatics, etc.

"Plate I, Fig. 2 is from a section taken from as nearly as possible the advancing edge, as seen by the naked eye. The muscle here has lost its contractility. Various normal fibers are seen, with characters as above, while others exhibit a very striking change. The staining reaction is different, being an almost uniform eosin tint, while the dots indicating the individual fibrils are lost. These fibers are not shrunken, but on measurement are often found to be somewhat swollen. In spite of this, however, these fibers are well separated off from the interstitial connective tissue, to leave what appears in the section as a clear space. Occasionally the separation of reticulum from fiber is partial, and confined to a sector only; but even in such instances the fiber still shows the uniform eosin tint indicative of degeneration. The sarcolemmal nuclei of the separated fibers still stain brightly. The contents of the spaces between the altered fibers and the interstitial meshwork will be discussed later, and it may simply be noted here that such fibers are obviously cut off from their blood-supply in the interstitial tissue. Plate II, Fig. 1 is from a section taken from the tissue $2\frac{1}{2}$ mm. to behind the one just mentioned, and in it all the fibers have undergone the degenerative change described above.

"The fibers are all separated off completely from the interstitial tissue which forms a regular network between them. The regularity of the network is in no way exaggerated in the drawing, and no difference would be observed in a color photograph of many of our sections. The nuclei of the sarcolemma are at this stage stained as in the normal fibers.

"In longitudinal sections of tissue taken to include the advancing edge, the process is less striking to the eye, as it is impossible to get complete lengths of fibers in any one longitudinal section. The appearances are quite easy to follow, however, having in mind the information obtained from the transverse sections. A fiber which stains normally can often be traced to a point where, quite suddenly and with a very definite edge, the color change to the strong uniform eosin tint is met with, and the normal striation disappears. Practically coinciding with the color change, which no doubt represents the margin of death of the fiber, the interstitial tissue is seen to separate off and leave the clear space which is so obvious and striking in the transverse sections.

"The significance of these observations may now be briefly dealt with.

"In transverse sections stained for organisms these are found far beyond the edge of the gangrene in the interstitial tissue between the healthy fibers. What then determines the advancing death of the individual fibers? The whole question seems to us to be bound up in the contents of the spaces left between the degenerated fibers and the meshwork of interstitial tissue. The altered fibers are not shrunken, and the muscle at the spreading margin is tumid and increased in bulk. This swelling is evidently due to the extra room taken up by the spaces described. It was a tempting view to take, that these spaces might be filled by gas alone, which, by the mechanical effect of pressure and by cutting off the fibers from their blood-supply in the interstitial tissue, might lead to their speedy death. Attempts were made to prove this view correct by cutting thick frozen sections of fresh unfixed tissues, and looking for evidence of gas under the microscope, but none could be detected. On the other hand, in tissues fixed in corrosive sublimate, and more especially in material fixed by boiling before being embedded in paraffin, evidences of amorphous deposit in the spaces were found, which seemed to point to the contents being a fluid. In tissues fixed in formalin, from which the drawings were made, the spaces almost invariably appeared quite empty and free from anything which stained. We, therefore, are of opinion that a toxic fluid, perhaps similar in constitution to the edema which always accompanies gas gangrene to a greater or less extent, spreads along between the interstitial tissue and the fibers, killing off the latter as it advances. Once the fibers are killed, the anaërobic bacilli live on them practically as saprophytes, breaking down the sugars and producing abundant gas. This process is in strong contrast to what occurs in healthy muscle, where the presence of the organisms is without effect on the living fibers.

"The rapid spread of the disease into living muscle can, we think, be explained on these lines. Fibers each of which stretch without interruption for a considerable distance are killed in the manner which has been described and the dead tissue is then rapidly broken down and gas is formed. The circle is a vicious one, for the toxic fluid which spreads between the fibers is no doubt formed in the gangrenous tissue behind, and so the condition spreads until the ends of the fibers are reached. This view also gives a satisfactory explanation of how single muscles may be found gangrenous, no spread having occurred to others close at hand. No opinion can yet be given as to the nature of the toxic fluid, which may either be a true bacterial toxin or something dependent on the breaking down of tissues.

"Other points brought out by histologic examination may now be referred to. With regard to the route followed by the organisms, these are, at the spreading stage, never found in the muscle-fibers themselves, but are practically confined to the reticulum (Plate II, Fig. 2). When the fibers are dead and are being broken down, the bacilli invade the disintegrating fibers in numbers. At a later stage (Plate III, Fig. 2) all

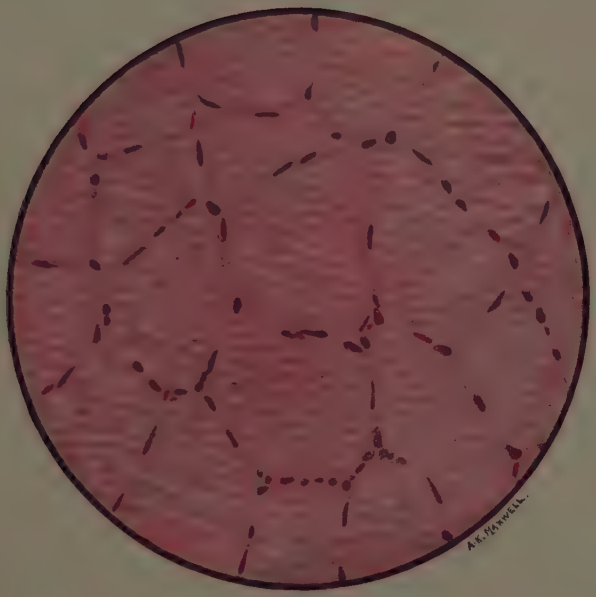

FIG. 1.—Normal muscle in transverse section, just beyond the edge of the spreading gangrene. (Hemalum and eosin.)

FIG. 2.—Muscle from as nearly as possible the visible advancing edge. Note the marked contrast between the dead coagulated fibers, which are separated off from their sheaths, and the paler normal fibers. (Hemalum and eosin.)

Plate I and Plate II, Fig. 1 represent the conditions found at different levels in a single block of tissue from the advancing margin of gas gangrene. Between Figs. 1 and 2, Plate I there is an interval of 2.5 mm. of length, and the same distance between Fig. 2, Plate I and Fig. 1, Plate II.

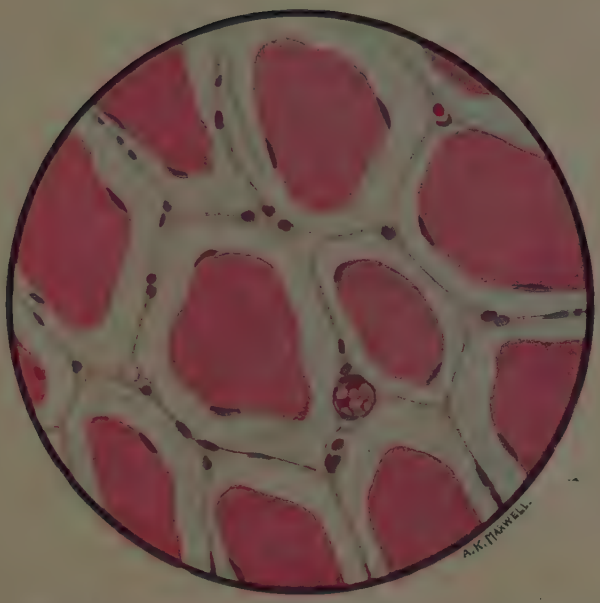

FIG. 1.—All the fibers are here degenerated, but their sarcolemmal nuclei still appear intact. Separation of the fibers from their sheaths is everywhere complete. (Hemalum and eosin.)

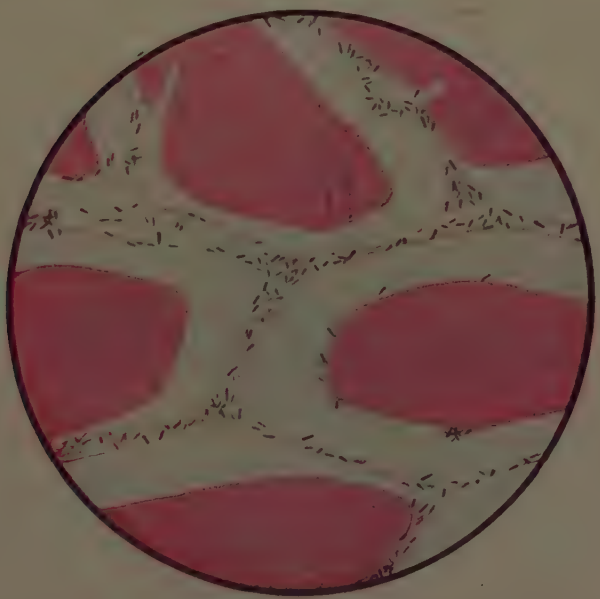

FIG. 2.—This shows the distribution of organisms at a comparatively early stage. There are large numbers of bacilli in the reticulum, but they have not yet invaded the fibers. This stage is slightly more advanced than that depicted in Fig. 1, and the nuclei of the sarcolemma have disappeared. (Leishman's stain.)

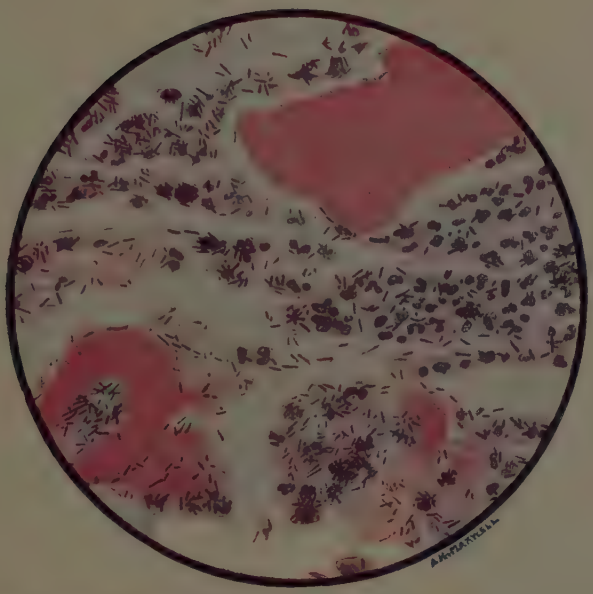

FIG. 1.—Phagocytosis of anaërobic bacilli in a zone where the process of gas gangrene has been arrested. The leukocytic reaction is in remarkable contrast with the previous figures. (Leishman's stain.)

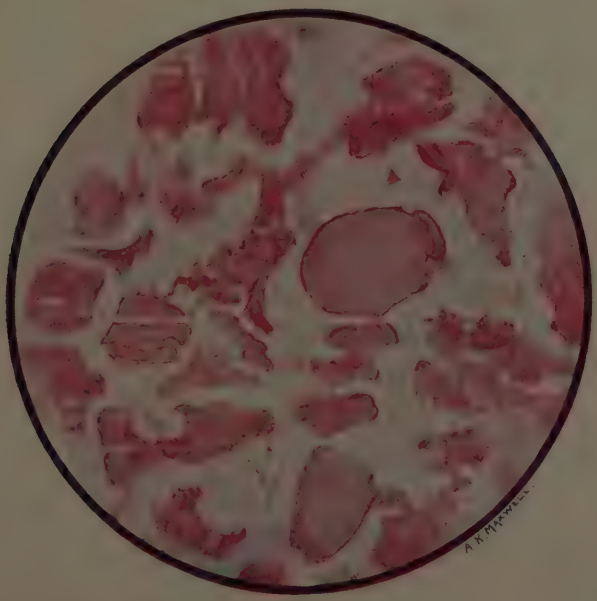

FIG. 2.—A late stage of gas gangrene, showing complete disintegration of muscular fibers and reticulum. In this material organisms were present in large numbers, and frequently in the substance of the fibers. (Hemalum and eosin.)

definite muscular structure becomes lost and gas is present abundantly between the remnants of the fibers. It is interesting to note that in muscle at this advanced stage of the disease the number of organisms appears much less than in the spreading zone. This is evidently partly due to many organisms staining badly, so that ghost forms are numerous. It seems probable that this stage, once reached, is inimical to the life of the bacilli, so that many are destroyed and disappear.

"In rapidly spreading gas gangrene leukocytes are generally conspicuous by their absence in the muscular tissue involved (although they may be present in some number in the interfascicular planes). The mere speed of progression of the process in muscle may probably account for this, as a leukocytic reaction takes some time to develop. Where the spread of gas gangrene is being arrested in muscle, great leukocytic invasion is present. This is well shown in Plate III, Fig. 1, taken from a muscle in an amputation stump. Here a recrudescence occurred in the stump, but was arrested after spreading a few inches only. Macroscopically a very definite pale zone was visible, and in section abundant phagocytosis of bacilli by polymorphonuclear leukocytes was found."

Generation of Gas.—The phenomenon of gas production which gave the name by which the disease was known in France is an important one from a clinical point of view, though the part it plays in the spread of the disease is but a secondary one. It is generated about the time that the muscle begins to change color. It produces swelling tympanites of the limb before it gives rise to crepitation which is discernible by the fingers, though even now, as pointed out by B. C. Maybury, a stethoscope may reveal a crackling if used with a varying pressure. At this stage the muscle floats if thrown into water. A little later the gas becomes obvious to the naked eye as bubbles lying between the fibers, and these bubbles can be displaced up and down the muscle by pressure. If the fascia of the limb is intact—or nearly so—the gas quickly increases the swelling and tension of the limb, and this tension is liable to render the skin white. If the gas can find no exit from the wound it is forced into the areolar tissue between the muscles. It follows the line of least resistance and finds its way along the great vessels, and by means of the perforating arteries reaches the subcutaneous tissue, through which it rapidly spreads far beyond the limits of the disease. When it reaches the skin the phenomenon of crepitation becomes especially marked. In some cases incision of the skin is followed by the escape of gas which burns on the application of a match.

The presence of gas can be demonstrated by *x*-ray photographs, and this means of diagnosis has been of use in subacute cases such as occur at the Base Hospitals. Owing to the fact that gas production in quantities that will show in an *x*-ray plate is a comparatively late phenomenon, this means of diagnosis cannot be relied upon in the acute cases such as are met with in the C. C. S.

Clinical Course.—When the wound is an open one it may simply present bruised and torn muscle. Very often, however, the appearance

is peculiar and the extruded muscle shows a dry, deep purple, or blackened surface, which at first sight suggests dried fecal matter.

Later on the wound becomes moister and there is a thin foul discharge mixed with bubbles of gas and droplets of fat. Still later the discharge becomes copious and bright yellow, the yellow color being produced by hemolysis. The amount of odor present is very various, but at times it becomes penetrating and overpowering. In such a wound infection may be purely local and the symptoms of absorption absent. When the disease really gains an entrance into the body it may be divided, for purposes of clinical description, into three groups:

(*a*) Group gangrene. (*b*) Segmental or massive gangrene. (*c*) Fulminating gangrene.

(*a*) and (*b*) correspond to the types of infection described under the gross morbid anatomy; (*c*) is a purely clinical type which may originate either in (*a*) or (*b*).

Early Symptoms Common to All the Above Varieties.—No case is immune in which muscle has been touched, even if the projectile be an undeformed bullet.

The onset may be extremely acute and constitutional symptoms and well-marked gas production present within four hours. A patient left in good condition may be found *in extremis* in a few hours. Many patients about whom the doctor had had no anxiety at night have been found in the morning in a dangerous condition, the infection gaining ground while the patient was asleep or without causing him to summon the nurse. The early symptoms are pain in the affected parts, a feeling of malaise and restlessness; a rise in the temperature and pulse-rate. Drummond and Taylor have pointed out that a rise in the blood-pressure may usher in the disease.

Vomiting may be an early symptom, and later on may become one of the most distressing phenomena of the disease.

Physical Signs.—Group Type.—The limb at first may show no departure from the normal or it may be swollen to a greater or less extent. The skin at first is normal, then becomes blanched and tense. The veins, as a rule, do not show up. The area around the wound or even the whole limb becomes tympanitic, or early crepitation may have already been detected by the stethoscope. In wounds which have been operated upon and which do not appear to be going on well, it is of importance to distinguish the resonance which has been produced by the entry of air into the wound from the resonance caused by the gas production. As the swelling increases the skin becomes dirty looking and the veins may become marked out. Mottling of the skin is noted, and purple patches appear which are caused by the cutting off of the blood-supply by the death of the underlying muscles. Finally the skin takes on a greenish-yellow hue.

It is important to remember that gangrenous muscles may be covered by perfectly normal skin. In certain cases a peculiar bronzing of the skin may be noted. It may occur near the wound or in some cases at a considerable distance. Its significance and cause have not been

This is a drawing made from a forearm which was amputated on account of gas gangrene. The projectile passed across the flexor aspect of the forearm, causing great laceration of the muscles. The whole of the muscles on the flexor aspect were gangrenous, the change being most advanced in the deep flexors and the supinator brevis, which were diffluent. There was in this case ample opportunity for direct infection of the different muscles. The main arteries were intact, so that the gangrenous process was entirely due to infection; in other words, it was not a case of infection after arterial death, but of infection producing total destruction of the muscles and consequently of the skin and subcutaneous tissues. The drawing speaks for itself and requires but little explanation. It shows the purple mottling of the skin, and the contrast between the infected flexor muscles seen through the wound and the normal-colored muscle by the side of the cut humerus.

fully explained. Its appearance may mean little or nothing or be the beginning of extensive sloughing of the skin and death of the patient. Incision into such an area may reveal little or nothing amiss or disintegration of the subcutaneous tissue.

Massive Type.—Gangrene of a segment of the limb from which the blood-supply has been cut off.

1. A limb already gangrenous suddenly becomes tympanitic and the patient shows the early common symptoms, such as pain, vomiting, and a rise of temperature.

2. The gangrene, tympanites, and clinical signs manifest themselves at one and the same time.

In both varieties the appearance of the skin is that seen in arterial gangrene, but infection of the bacteria produce a rapid appearance of the signs of decomposition.

Fulminating Type.—This clinical type is exceedingly dangerous. Surgical measures such as are sufficient to save life and limb in the first two are often unavailing. At first it cannot be distinguished from the "group" or "massive" type, and it is only the failure of surgical treatment to arrest the disease which reveals its nature. It is often seen in a thigh amputation for an infected wound of the leg. Here amputation through apparently normal tissue is followed after perhaps a few hours of apparent amelioration by recrudescence of the disease, which extends rapidly on to the body and proves quickly fatal. It is in this type that the gangrenous process in the skin can be followed from hour to hour.

Late Common Symptoms.—If the disease is not sufficiently acute to cause death in a short time, the skin of the whole body first becomes dirty looking and then yellow, the yellow color being very noticeable in the whites of the eyes. This universal discoloration of the skin was perhaps more obvious in the earlier part of the war when the surgical treatment was not properly understood. If cases do not progress favorably all the symptoms undergo an aggravation. The pulse becomes more rapid—then running; vomiting is frequent and exceedingly distressing; the extremities become cold and blue, the body covered with sweat, and the temperature, which has been raised, falls. This fall in temperature was sometimes, in the early part of the war, regarded as a favorable sign, though it really ushered in the end. The mind remains, as a rule, extraordinarily acute even to the end.

Treatment.—There are two most important things to be noted:

1. The avoidance of all things that tend to restrict the blood-supply, whether those be constriction by tourniquet, tight bandaging, continued damage caused by inefficient splints, the damming back of discharges by dressings, or the persistence of shock.

2. Mechanical cleaning of the wound at the earliest possible moment. The importance of early surgical interference became more and more obvious as the war went on. In the end it became to be recognized that not only was it necessary to get the wounded man quickly to the C. C. S., but that the cutting short of the resuscitation period

of those too bad at first for operation was imperative. In the shortening of this period the infusion of gum saline or blood played a greater and greater part. The actual treatment of the patient is governed by two conditions: (1) the state of the patient, (2) the extent of the gangrene.

Thus a patient who is in good condition can be submitted to an operation for eradication of the diseased muscles, while in another patient the same amount of disease may demand amputation.

The surgical measures to be adopted are best considered as follows:

1. Group gangrene. 2. Massive or segmental gangrene.

1. Group Gangrene.—(The patient in good condition.) The mechanical cleaning of the wound is proceeded with in the usual way, adequate longitudinal incisions being used. Great gentleness is necessary and care must be taken to respect even small blood-vessels, otherwise another portion of the muscle may be deprived of its blood-supply and be found later dead and infected. Attention is focused on the condition of the muscles. All muscles that do not contract or bleed, or are altered in color, are removed. Certain muscles may be required to be followed to their attachments. By this means a limb may be saved—at the expense of a muscle or muscle group—which would have been sacrificed if crepitation and tympanites had been taken as the criterion of the extent of the disease.

2. Group Gangrene.—(The patient in bad condition.) This is most likely to occur in fractures of the long bones. Here the limb will most probably have to be taken off through the fracture. If it is thought that a higher amputation is indicated by a tympanitic condition of the skin, it is well to investigate the condition of the muscles by skin incisions, starting at the level of the injury and ascertaining that they are dead at the level of the proposed amputation. Under war conditions it is seldom justifiable to amputate through the thigh for a gas gangrene of the leg. In many cases it must be recognized that the amputation is a provisional one, and greater care must be taken to provide the opportunity of later on fashioning serviceable stumps than to attempt to fashion a permanent stump on the first instance. A guillotine amputation through the head of the tibia or through the knee-joint—preferably the former—with removal of the heads of the gastrocnemii is usually sufficient.

Massive or Segmental Gangrene.—This type is usually met with after injury to a main artery. Suture of the artery or, if this is not possible, the use of Tuffier's tubes are to be recommended as prophylactic measures.

When the gangrene is established and the limb obviously dead, it is only a question of where to amputate. Here again the state of the muscles is the guide, and the limb should be removed at the lowest level of the living muscle. In some cases where there is a gross injury, such as a shattered joint or a fracture of a long bone, it may be necessary to disregard the extent of the gangrene and to amputate at a higher

PLATE V

This represents a dissection of the thigh of a man who died from multiple injuries and gas gangrene of the thigh. A wound is present over the vastus externus, part of which has been carried away. The resulting dirty cavity can be seen, as can also the infected subcutaneous tissue, which is of a dirty yellowish-green hue. The vastus externus, although wounded, did not become gas-gangrenous; this may be attributed, perhaps, to the open nature of the wound. The missile passed behind the rectus tendon, and was found lodged against the fibers of the vastus internus. The point of interest lies in the condition of the latter muscle, which was gas-gangrenous throughout. The change in the color of the muscle is a subtle one, but can be easily seen. Although not so apparent in the reproduction, the same change was present in the outer edge of the lower part of the sartorius, just where it lay in apposition to the vastus externus. The color of the vastus externus is altered from the normal red-purple to a brick-red. The whole muscle was dead and non-contractile, and some bubbles of gas were visible between the fasciculi. It is to this stage that I have given the name "red death." The other muscles of the thigh were not affected. Death occurred in this case fifty-six hours after the wound was received, and the condition of the thigh was found at the *postmortem* examination.

The intermuscular connective tissue showed but little alteration in this specimen. This is often the case, but at other times there are distinct alterations. Gas may be found abundantly along the great vessels, and also commonly in the subcutaneous tissues. It is important to note that cultures from such gaseous tissues may prove sterile. At other times the connective tissue is edematous without being discolored, and occasionally the appearance is distinctly gelatinous. Later, the edematous tissue takes on a yellow or yellowish-green color, but still remains transparent.

This exhibits the changes in the subcutaneous tissues in a striking degree.

In this case there was a compound fracture of the humerus just above the elbow-joint, and, in addition, a penetrating wound of the chest. The patient's condition was so precarious that amputation was considered the best course, especially as there was no radial pulse.

The case is a beautiful example of the involvement of a single wounded muscle, and would have been an ideal one for a local excision had not the arm been shattered and the man's condition dangerous. The supinator longus is seen in the diffluent stage of gas gangrene. The muscle was yellowish-green in color, and quite devoid of form or tone. It was so soft that it could be molded or dented with the finger. The greenish-yellow coloration and edematous state of the subcutaneous tissue are well seen, although before the skin was reflected the external appearances were not marked. The other muscles of the forearm, as can be seen in the drawing, were normal and still readily contractile when examined.

level than the injury. Amputation through the knee-joint, or head of the tibia, is to be preferred to amputation through the thigh.

Method of Amputation.—Except in cases of grave danger short flaps of some description should be furnished. Below the knee, where the amputation will almost always be of a provisional nature, the guillotine method is often the best. In all amputations under war conditions it is probably better to leave the flaps open or to lightly suture them over gauze. A non-closure of the flaps has also the advantage that for the next day or two the surface of the stump can be inspected, and this will render more easy the excision of the muscles which sometimes are found dead within a few hours after the amputation.

Fulminating Type.—This type is seen generally after amputation through the thigh. It is practically hopeless. It need only be said that reamputation in these cases at or near the hip is almost uniformly fatal and should only rarely be undertaken.

Treatment by Sera.—Sera were used on a small scale both by the French and the Germans in a comparatively early part of the war, but it was not till 1918 that this treatment was used by the British. At this period a fairly extensive trial took place both in the French and British armies.

Even when different sera were available in suitable amounts the difficulties of arriving at a balanced judgment of their efficiency were very great. This was owing to the following causes:

(1) The almost universal mixed infection of wounds. (2) The want of an accurate knowledge as to the varieties of anaërobic organisms causing the disease. (3) The want of a means by which an early diagnosis of the actual organism causing the infection, in any particular case, could be made. (4) The lack of standardization of the sera.

The sera used in the British Army were those prepared against B. welchii and Vibrion septique. They were antitoxic sera. They were used therapeutically and in a certain sense prophylactically.

Treatment by Sera (2).—Early in 1918 Major Carrol Bull of the United States Army was attached to the British Army in order that he might make a trial of his antitoxic B. welchii serum.

This was administered in the C. C. S. to cases that had already developed the disease; its use was, therefore, therapeutic. It was given, as a rule, intravenously (supplemented by subcutaneous and intramuscular injection) in doses up to 80 c.c., and repeated in some cases. In some cases observers were struck with the improvement produced, but it cannot be said that the results were at all uniform.

Later on other sera prepared in England against the B. welchii and Vibrion septique were used with very much the same effects.

In June, 1918 a trial on a large scale was made of a combined antitetanic and antiwelchii serum. This serum was used in what may be described as a prophylactic method. The trial was made in the part of the line that ran north from Bethune. Certain divisions were supplied with the combined sera, while those next door were given the antitetanic serum only. These sera were administered in the Advanced

DESCRIPTION OF PLATE VII

In the small segments of muscle shown in Figs. 1, 2, 3, and 4 it is possible to trace the color changes in greater detail. All the pieces shown were taken from the gluteus maximus muscle except one (Fig. 4), which is a portion of a tibialis anticus muscle.

Figure 1 is drawn to represent the normal color of gluteus maximus muscle, the actual specimen being taken soon after death from a patient who died of acute peritonitis. The normal color, sharpness of outline, and general appearance of the fasciculi show that the muscle was healthy.

Figure 2 shows a piece of muscle which was dead, non-contractile, crepitant to the touch, and brick-red in color. The bubbles of gas, or rather, the spaces once occupied by them are distinctly seen. In this stage the muscle is very friable, and by gentle stroking the gas can be pushed about from place to place between the fibers.

Figure 3 shows a piece of muscle from the tibialis anticus at a further stage in the gangrenous process. The color is now passing gradually from brick red to an olive green. The tissue has become more friable, and the consistence may almost be described as "putty-like."

Figure 4 exhibits an end-stage, which is not often seen at operation. The color of the muscle is a greenish black, and the surface is glistening. Such a piece of muscle is so soft that it tends to flatten out and spread over the surface on which it is placed.

In Plate VI the condition of the supinator longus is intermediate between the stages depicted in Figs. 3 and 4 respectively.

PLATE VII

FIG. 1.

FIG. 2.

FIG. 3.

FIG. 4.

the damaged muscle. If after investigation it was considered that one or the other of the three organisms was predominant the appropriate antiserum was pushed.

Used in the above manner, the sera produced a very favorable effect on the minds of the French surgeons and the reports were somewhat enthusiastic.

Finally, it may be said that while the experience of the French and British services differed as to the efficacy of the serum, all observers were of the opinion that every effort should be made to continue and enlarge the application of the treatment.

[For the use of the colored illustrations of gas gangrene our best thanks are due to the British Medical Research Committee, to their artist, and to the editor of the British Medical Journal.—W. W. Keen.]

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CHAPTER VII

TETANUS*

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Large as has been the clinical experience of the war and intense as has been the laboratory study of the problem of tetanus, no real addition has been made to the fundamental knowledge which existed August 1, 1914 concerning this disease.

Summary of Bacteriology and Pathology.—For a consideration of the discussion of the knowledge of tetanus at the beginning of the war the reader is referred to the article in Vol. I, page 478, of this System of Surgery, by Dr. Charles Harrison Frazier. There will be found an account of the observations summarized in the paragraphs immediately following, which have marked the study of this disease which Sternberg[1] in 1880 was able to produce experimentally in animals by the injection of gutter water and earth, and which four years later Carle and Rattone[2] transferred to animals by the injection of pus from the wounds of cases suffering from tetanus. Nicolaier[3] in this same year identified the long and slender bacillus of tetanus with the bulbed end, and described also essential characteristics of its habitat and growth on culture-media, but it remained for Kitasato[4] in 1889 to isolate pure cultures and recognize that the spore of tetanus had unusual power of resisting heat and that the organism was anaërobic. These bacteriologic facts remain uncontroverted, and the organism described by Nicolaier is accepted as the cause of tetanus.

Captain Tulloch,[5] working on behalf of the British Tetanus Committee, has been able to differentiate four types of tetanus bacilli. This differentiation has been made by agglutination tests. An examination of 100 cases suffering from clinical tetanus showed 41 to be of Type 1; 20 of Type 2; 35 of Type 3, and 3 of Type 4. So far as known the antitetanic serum prepared in the routine way has the same effect for all types, neutralizing the toxins of any one or of all. These different types will be referred to later in the discussion of the incidence of cases in which tetanus organisms have been found in men not suffering clinically from tetanus, and also in relation to the death-rate, but they are mentioned here because this is, so far as I know, the single real addition to the bacteriologic knowledge of the disease which has been contributed by studies during the war.

The laboratory observations on the fate of bacteriologic spores in the animal body by Koser and McClelland,[6] reported in 1917, are of

*Supplementary to Chapter XII, Vol. I, p. 478, and Chapter LXXXIX, Vol. VI, p. 61.

particular interest in view of the late development of the clinical symptoms in many of the reported cases. These observers find that *the spores of the Bacillus tetani may persist in experimental cases at the site of inoculation for four months and in the liver and spleen for two months.* This observation has great clinical importance and shows clearly the possible danger of surgical interference or manipulation in cases of encapsulated foci of tetanus, unless preceded by another prophylactic dose of the antitoxin.

Having isolated the organism, Behring and Kitasato[7] demonstrated that animals protected by an antitoxin were given an immunity against the toxin generated by tetanus. Behring[8] in 1892 immunized horses and began the manufacture of antitoxin on a commercial scale. From the first they recognized the great power of immunization and were inclined to believe that there was a considerable curative effect also from the antitoxin. Whether the reaction is a simple chemical one in which the toxin is neutralized by the antitoxin, as was held by these two investigators, and is supported by Rosenau,[9] or whether the antitoxin is affected after having passed through the circulation, is immaterial.

The fundamental and prewar observations of Marie and Morax[10] and Meyer and Ransom,[11] which determined the fact that the toxin which was produced locally by the tetanus bacillus was carried to the cord by the axis-cylinders of the motor nerves, the sensory fibers never taking part in this transmission, remains uncontroverted. A toxin which enters the general circulation is diffused through the capillaries and later brought in this way to the motor nerve endings.

The researches of Fletcher[12] on *tetanus dolorosus* demonstrate clearly that the tetanus toxin must be injected directly into the posterior spinal ganglion in order to produce *T. dolorosus*, and that no sensory involvement can result from the transmission of the toxin in the peripheral sensory nerves. His experiments also demonstrated the difficulty of differentiating between the toxin which may be circulating freely within the lymphatic vessels of the nerve, but without combination with the nerve substance, and the toxin actually in combination within the axis-cylinder. Tetanospasmin and tetanolysin, while recognized as specific tetanotoxins, have not been considered individually in treatment.

Histologic evidence would indicate that such changes as have been reported in the peripheral and central nervous systems were associated with infection rather than caused by a specific action of the toxins of tetanus.

Practical interest in the study of cases developing tetanus during the war, either as isolated observations or as studies in the analysis of large series of cases, has centered about two questions: first, the recognition of the various types of tetanus infection; second, and most important, the prevention and treatment of tetanus.

Symptoms and Types.—In the symptomatology of acute tetanus the clinical observations of early surgical writers remain unmodified; in fact, the description of tetanus given by Larrey, in his "Memoirs of

Military Medicine," are so graphic and accurate that it is difficult to realize that there existed at that time no knowledge of the bacteriologic origin nor a concept of the pathology of tetanus. His recognition of the infected upper layers of the soil and the particular dangers of stable-yard dust is almost prophetic.

On the other hand, the experience of the recent war has contributed much in the recognition of atypical forms of tetanus. *Cephalic tetanus* of the four types, without paralysis, with facial paralysis, with paralysis of the motor nerves of the eye, and with paralysis of the hypoglossal nerve had been recognized for years. Rose in 1872 described cephalic tetanus, and general surveys had been made of the various types by Villar, Albert, Janin, Reclus, Poan de Sapincourt, Wald, Wurms, and others, but it required the exigencies of the war to force a resurvey of this field and a recognition of the importance of these atypical forms.

The summary of the different forms of tetanus given by Courtois-Suffit and Giroux[13] is so complete and so accurate that it is given in full.

"CLASSICAL FORM

"Incidence.—Since the introduction of preventive serotherapy, less frequent than formerly. Statistics relating to present war show that frequency may vary from 11.8 per 1000 (Bazy) to 0.1 per 1000 (Valette).

"Symptomatology.—A usually brief prodromal period is observed in four-fifths of the cases, and is characterized by neuralgic pains in the vicinity of the wound, and dull or shooting or sometimes fulgurant pains along the course of the nerves in its neighborhood, with spasms, stiffness, and slight and transitory contractures of the various muscles of the wounded area. The subject is next attacked by trismus. Then the neck muscles become stiff; dysphagia appears; the facial muscles are affected, causing *risus sardonicus*. The body is arched—opisthotonos.

"The muscles of the abdomen become contractured, then those of the limb. The entire body now becomes completely rigid. The contractures are usually intermittent, but recur on the slightest movement or stimulation. Occasionally contracture is localized to trismus without generalization.

"High fever—104° F. up to even 107.5° F. Often there is retention of urine.

"Lastly, the respiratory muscles are affected and the patient succumbs to asphyxia.

"Sometimes emprosthotonos, pleurothotonos, or orthotonos replace the opisthotonos.

"Diagnosis.—Easy when symptoms are complete. If trismus is the only sign at outset, eliminate: (1) Mental affections and angina. (2) Acute strychnin-poisoning gives rise to similar symptoms.

"Prognosis.—Grave. Mortality despite serotherapy is still high. Recent statistics show a death-rate amounting to 64 per cent.

"ABNORMAL FORMS

"A. **Splanchnic Tetanus.—Incidence.**—Very rare. It occurs in man quite exceptionally after abdominal operations or uterine wounds.

"Symptomatology.—Long incubation. Short duration of the malady.

"Non-generalization of the contractures which involve the muscles of deglutition and respiration. Dyspnea is marked and always alarming.

"Diagnosis.—Eliminate hydrophobia.

"Prognosis.—Always fatal.

"B. **Cephalic Tetanus.**—(1) **Non-paralytic Type.**—*Incidence.*—Very rare. No signs of facial paralysis. Always wound of head.

"*Symptomatology.*—(*a*) Simple cephalic tetanus. Trismus only with contraction of certain face muscles.

"(*b*) Dysphagic form. Pharyngeal spasms rendering alimentation difficult. Sometimes respiratory muscles affected.

"(*c*) Hydrophobic form. Violent convulsive spasms, starting in wound, radiating to muscles of neck, face, and pharynx, finally reaching the diaphragm, causing grave respiratory disturbance.

"*Diagnosis.*—Eliminate true hydrophobia in types (*b*) and (*c*).

"*Prognosis.*—Type (*a*) grave. Still more gloomy if respiratory disorders appear. In the dysphagic and hydrophobic forms nearly always fatal.

"(2) **Paralytic Type.**—*Incidence.*—Rare. Follows a wound of head in the region innervated by the trigeminal.

"*Symptomatology.*—Facial paralysis with contractures localized principally in the cephalic region, above all, in the facial region, but the tetanus may slowly invade other regions.

"Facial paralysis may precede, follow, or accompany the contractures. It is usually unilateral, occurring on the same side as the wound. If the wound is median, there may be facial diplegia. The paralysis may be partial or complete. Complete facial paralysis affects the whole seventh nerve, and may cause hyperacusis and disorders of taste. Partial facial paralysis may involve either the upper or lower branches of the facial nerve.

"*Diagnosis.*—Differentiate it from (1) direct traumatism involving the facial nerve; (2) hysteria; (3) tic douloureux; (4) traumatic reflex spasms.

"*Prognosis.*—Less gloomy than in usual forms of tetanus. Mortality in France does not exceed 50 per cent. The facial paralysis usually disappears without leaving permanent traces when the patient recovers from the tetanus.

"(3) **With Paralysis of the Motor Nerves of the Eye.**—*Incidence.*—Comparatively rare. Occurs when tetanus follows trauma of the eye and adjacent parts.

"*Symptomatology.*—Occasionally ocular paralysis is earliest manifestation. The third nerve is always involved; the fourth and sixth also may be paralyzed. Ptosis, strabismus, and a more or less complete paralysis of the external muscles of the eye are the ordinary symp-

toms. The internal muscles of the eye may be affected also. This form may coexist with facial paralysis.

"*Diagnosis.*—Differentiate it from (1) ocular spasms; (2) cerebrospinal meningitis; (3) tuberculous meningitis; (4) fracture of the orbit; (5) fracture of the base of the skull.

"*Prognosis.*—Cases of ophthalmoplegic tetanus have been fatal. Chronicity is in favor of recovery. The prognosis of the ocular paralysis *per se* is good. In only one case did the ophthalmoplegia last three months.

"(4) **With Paralysis of the Hypoglossal (Rare).**—*Symptomatology.*—Syndrome of labioglossolaryngeal paralysis.

"C. **Unilateral Tetanus.—Incidence.**—Existence debated. In any case, exceedingly rare.

"Symptomatology.—In general the symptoms are for some time confined to one side of the body, and are still predominant there during generalization, giving rise to pleurothotonos.

"Diagnosis.—Differentiate it from irritative cortical lesion.

"Prognosis.—That of the classical form of tetanus.

"D. **Tetanus of the Limbs.**—(1) **Monoplegic Form.**—*Incidence.*—Rare. Observations more frequent since first case published by Courtellement.

"*Symptomatology.*—The first symptoms consist of a slight stiffness either of the muscles of the wounded limb or the masseters. The onset may be early or late. The first signs are usually pain in the wounded limb, soon followed by a localized contracture, or the contracture may be the first symptom, the limb feeling, on palpation, like a mass of wood.

"Sometimes there is slight transitory trismus. There is little or no stiffness of the neck. There is often a more or less marked contracture of the abdominal muscles.

"There is little fever. Temperature is about 100.5° to 101.5° F. The pulse is moderately rapid—100 to 120 per minute. Not irregular. The facial expression is anxious.

"There is constant exaggeration of the deep reflexes, often with ankle and patellar clonus, and hyperexcitability of muscles and nerves under electric stimulation.

"*Diagnosis.*—Differentiate it from (1) spasmodic monoplegia due to cerebral or medullary lesion; (2) irritation of motor and mixed nerves; (3) contractures due to lesions of bones and joints; (4) tetany; (5) hysteric contracture.

"*Prognosis.*—If development be chronic, there is a tendency toward recovery. The prognosis is, however, grave on account of possible complications or secondary generalization.

Routier observed 6 cases with 3 deaths. Nevertheless, it often tends toward recovery, except in cases of late postoperative tetanus.

"(2) **Paraplegic Form.**—*Incidence.*—Rare.

"*Symptomatology.*—According to the seat of the contractures one may distinguish: (*a*) Superior paraplegic form. Upper arm, forearm,

and hands forcibly flexed. (*b*) Inferior paraplegic form. Limbs in forced extension. Foot in position of talipes equinus. Lower leg extended from the thigh, the patella strongly immobilized. The thigh extended at the pelvis. The whole limb hard, as if petrified.

"*Diagnosis.*—Differentiate it from tetany, hysteric parapelgia, lesion of cord.

"*Prognosis.*—Favorable. Recovery the rule.

"E. **Localized Tetanus—Abdominal Thoracic Type (One Case).—Symptomatology.**—Tetanus confined to the abdominothoracic muscles. Not affecting other groups of muscles except masseters, which are slightly affected.

"F. **Attenuated Tetanus Developing Slowly After a Prolonged Incubation (Very Rare).—Symptomatology.**—The first symptoms consist of a slight stiffness, either of the muscles of the wounded limb or the masseters. The facial expression is abnormal.

"The general condition remains excellent, and the patient is able to walk. Muscular hypertonia without paroxysmal contractions. Temperature normal. Exaggeration of the deep reflexes and excessive excitability of the muscles and nerves to electric stimulation.

"**Diagnosis.**—Differentiate it from hysteric conditions.

"**Prognosis.**—Good."

Particular credit must be given to the French observers for the recognition of and an appreciation of the importance of the so-called localized tetanus, the relative frequency during the war resulting from the partial immunity afforded by the prophylactic injection of antitetanic serum. Interest in this type of the disease increased as the war progressed, and as attention was focused upon the possibility of a true local tetanus the percentage of cases reported materially increased. In many cases the clonic and tonic spasms of the muscles in the region of the wound were so characteristic that the diagnosis when once suggested was unmistakable. In other cases these local signs might be accompanied later by symptoms more or less severe of a generalized tetanus. Other cases which showed simply atypical twitchings or a persistent hardness supposedly due to muscle spasm in the region of the wound were undoubtedly confused with hysteric spasm or with muscle irritability due to improper splinting.

In the strictly localized cases recovery was the rule, so that not infrequently the diagnosis must remain a question of opinion. I recall one observation which was demonstrated to me in a hospital in France, in which the surgeon in charge was convinced that he had to do with a local tetanus, while I felt quite sure that proper splinting would have controlled the irritability of the muscles, caused by an improperly splinted high fracture of the thigh. It should be remarked, however, that injury to the patient is done only by failure to recognize the condition and to institute treatment; hence, overapprehension in these cases is to be encouraged rather than the tendency to minimize the possibilities of true local tetanus.

INCIDENCE

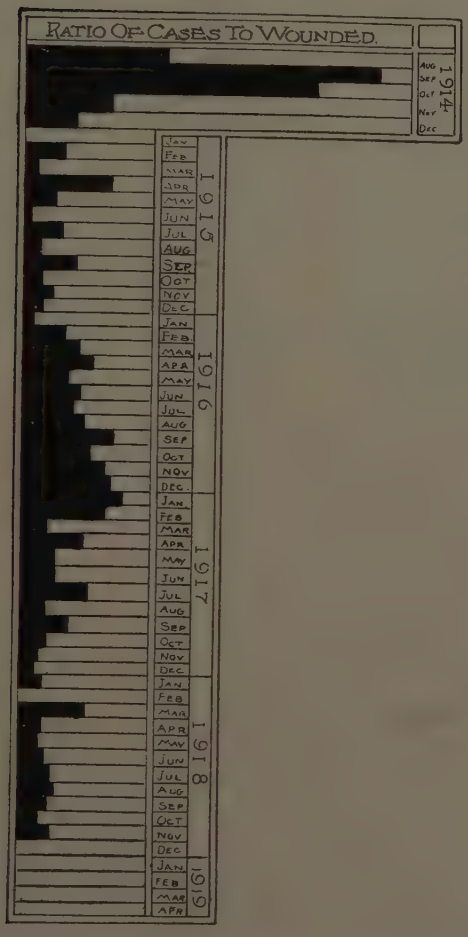
Before discussing the question of prevention and treatment let us consider the possible incidence of tetanus in wounds. Factors which have been of importance in determining the incidence in civil life, such as postoperative tetanus, from catgut, tetanus following the use of diphtheria and plague antitoxins, and associated with vaccination, may be disregarded, as no instances of such cases are recorded. The Surgeon-general,[14] in the History of the War of the Rebellion, reports 505 cases as having had tetanus, an incidence of about 2 per 1000 wounded. The incidence[15] among 95,000 cases of wounded reported by the Germans in the Franco-Prussian War was 0.36 per cent. In the South African War[16] it is reported by Stevenson that only 3 cases occurred in this campaign, and in the reports of the observers of the Russo-Japanese campaign tetanus attracted little attention, Von Oettingen stating that it was comparatively infrequent in summer, but that after the battle of Mukden approximately 1 per cent. of the wounded died of tetanus, this frequency being ascribed to the unusually unsanitary conditions which prevailed at that time.

Pathologic knowledge and the analysis of the experience of Fourth-of-July celebrations as reported in the Journal of the American Medical Association by Wells, forecast a very high incidence of tetanus in the Great War. The character of the ground on which the engagements were being fought, it having been highly cultivated and fertilized, the unusual nature of the fighting in trenches, the general use of high explosive shells which caused exceptional lacerations and contamination with earth and detritus, the weather conditions, and the difficulty of treating and transporting early such large numbers of wounded, all were factors conducive to an increase in the percentage of cases suffering from tetanus. In addition to the high percentage of wounds into which tetanus bacilli were undoubtedly carried, another factor influenced materially in the first phase of the war both the early incidence of tetanus and the results of serum treatment. That was the too conservative treatment of the wound by the surgeons. This fact is commented on by writers reporting on the Allied as well as the enemies' armies.

Table No. 1, compiled by Major-General Sir David Bruce,[17] of the British Tetanus Committee, shows graphically the incidence of cases of tetanus per 1000 wounded which were observed in England during the war. This table does not include the acute cases which developed in France, but the rise and fall in the incidence of these cases would probably coincide closely with that shown on the chart (p. 103).

The French experience as analyzed under different conditions by Bazy and Vallette[18] gives the incidence of tetanus as varying from 11.8 per 1000 to 0.1 per 1000. MacConkey[15] reports an incidence of 0.65 of tetanus in 83,593 cases of war wounds which had been reported by sixteen different writers from Allied and enemies' countries. While no definite figures were given, the opinion prevailed with the British

TABLE No. 1



Expeditionary Force that the incidence of tetanus increased when the fighting took place in wet weather.

PROPHYLACTIC TREATMENT

During the first stage of the war the use of routine prophylactic injections of antitetanic serum was not possible because of the limited supply of serum and lack of organization, nor was the necessity for this routine fully appreciated. At once the medical service of all armies found that an alarming number of cases developed tetanus. Every effort was made to establish a routine by which every wounded man received a prophylactic injection of 500 units U. S. A. with the British, and with the French forces 10 c.c. of serum, which equaled about 600 units U. S. A. The injections were given as soon after the injury as possible. Each patient, after receiving an injection, was marked or

ticketed in some way, and at the medical formations situated further to the rear, the checking to discover any cases in which the prophylactic injection had been omitted was considered a most important duty.

At once the number of cases developing tetanus *decreased rapidly* (see Table No. 1). At this period the opinion was expressed by medical authorities that with the improvement of surgical technic and with the routine injection of prophylactic doses of serum in all cases, tetanus would be absolutely eliminated.

Striking as was the decrease in the incidence of tetanus, this hope was not realized. It was found also that certain cases which had not been wounded, but in which there had been abrasions or blisters of the skin, developed tetanus. These were the cases of trench feet, and until this condition was recognized as a possible portal of infection by the tetanus bacillus the incidence of tetanus cases occurring was startlingly high. *Immediately upon the appreciation of this danger prophylactic injections were instituted in these cases as well as the wounded, and in them tetanus practically disappeared.* Doubtless a failure to appreciate minute portals of entrance has led in the past to the discussion of the so-called idiopathic tetanus and the supposition that certain cases had been infected by tetanus organisms in the respiratory or gastro-intestinal tracts.

DEGREE AND DURATION OF IMMUNITY

Very soon the question was raised as to whether the initial dose was sufficiently large to afford adequate immunity. The studies of MacConkey and Homer[20] are particularly interesting. They determined that 500 units U. S. A. did afford a satisfactory immunity for about a week, the degree of protection decreasing rapidly after that time, and disappearing almost completely at the end of two weeks. At the end of three weeks it was practically gone. The problem was how to continue this satisfactory immunity. Experiments indicated that an increase of the amount of serum up to the limits of practical use did not have an appreciable effect on increasing the duration of the immunity. To increase the immunity materially the amount of serum necessary for the single initial dose was prohibitively large; therefore they agreed with the conclusions of Levin, drawn in 1909, that it was only by repeated injections of the serum that immunity could be continued practically.

While the experimental evidence seems without exception to support the dictum that 500 units U. S. A. is sufficient for an immediate protective immunity, the British Medical Service[21] in 1917 recommended that the number of units given at the initial dose should be increased from 500 to 1000—1500 units in all deep wounds which were contaminated with dirt and in which there was a fracture of the bone. They recommended also in that same year, as had the French Service de Sante,[22] that repeated injections should be given to all seriously wounded men at intervals of seven days until they had received four. Both of these practices were adopted by the American Medical Service.

Theoretically these recommendations, particularly that of the multiple reinjections, should have resulted in both a decrease in the incidence of tetanus and a lowering of the mortality. While individual series of cases might seem to substantiate or disprove this, the reports of the British Tetanus Committee for Military Hospitals in Great Britain show no appreciable effect in the final analysis of a large series of cases from the larger doses or from the repeated injections, but the facts available indicate that the *death-rate in those contracting tetanus falls as the number of prophylactic injections increases.* The committee, therefore, recognize the use of multiple immunizing injections.

The importance of the time intervening between the wound and the prophylactic injection is graphically shown by a comparison of cases in which a preventive dose was received within the first twenty-four hours with that of a group in which the prophylactic injection was received after twenty-four hours. Of 43 cases receiving the prophylactic dose within twenty-four hours, 62.7 per cent. died; of 23 cases receiving the prophylactic dose after twenty-four hours, 86.9 per cent. died. Sir William B. Leishman and Major Smallman[23] recognize that other factors, such as liability to gangrene and severe sepsis, may have influenced the mortality in this series of cases, but they confirm the accepted opinion that time is a very essential factor in determining the success or failure of the antitetanic serum.

On the question of the prophylactic use of the antitetanic serum all the authorities are agreed. While 500 units should afford protective immunity, no harm was done by the use of larger amounts, and, as has been seen, the dosage was increased to 1000–1500 units. The routine of reinjections at intervals of seven days also found general favor. Because of the exigencies of the conditions under which the early injections had to be given, there was no possibility of discussion as to the merits of the different routes, the subcutaneous or intramuscular alone being practical. So frequently was acute tetanus observed following late surgical interference or manipulation that *it became the accepted rule also to always give prophylactic injections of the antitetanic serum before attempting the slightest surgical interference.*

TREATMENT OF CLINICAL TETANUS

It is only when we come to consider the problem of the treatment of tetanus after the symptoms have developed that we find widely divergent views. The general statement may be made that the more limited the opportunities for observation, the more positive are the views expressed as to the efficacy of this or that remedy or method in the treatment of tetanus. The opinions of individual observers based upon small series of cases continue to vary almost as widely as in the days of the Civil War, when, without knowledge of the bacterial origin of the disease or of any possible protection by immunity, the Surgeon-general in his report gives a list of drugs numbering nearly thirty which had been advocated in treatment and, in addition, to which great virtue

had been attached to the application of blisters, fomentations, ice, electric currents, etc.

While recognizing the fact that necrotic tissue and foreign bodies might foster the growth of the tetanus organism, clinical experience proved rather definitely that operative interference was contraindicated in cases in which symptoms had developed. By operation there seems to be great danger of overwhelming the patient by the opening up of new avenues of absorption.

The treatment by the use of sedatives can do nothing except to assist in the control of the convulsions. The bromids, chloral, chloretone, and morphin have a distinct place, and without doubt a proper appreciation of the value of these sedatives, combined with efforts to support the general condition of the patient, may influence the prognosis in cases seeming to die of exhaustion. Magnesium sulphate given in 25 per cent. solution intraspinally is recommended by Meltzer,[24] and persulphate of sodium given intravenously in neutral 5 per cent. solution as recommended by Lumière[25] controls the convulsive spasms perhaps more completely and more quickly than any other treatment.

It should be borne in mind, however, that both of these drugs so given are powerful depressants, particularly the magnesium sulphate, and this depressant influence may exert a distinctly harmful influence upon the patient.

The treatment by injections of carbolic acid, which at one time seemed to offer such possibilities, gave no encouraging results.

Experience in civil practice had indicated that uncertain as might be the prognosis in an individual case, the use of the antitetanic serum in large amounts had seemed to lower the mortality rate. If the established facts regarding the tetanus toxin are accepted, that is, that the toxin is produced locally, is carried via the motor nerves to the spinal canal, that *when once in combination with the nerve-cells it cannot be affected by the antitoxin*, it is difficult to appreciate why these large doses of the serum should influence the prognosis. Also it is difficult to see why the specific point of injection influences the course of the disease, unless the massive injection of the antitoxin in the region of the wound or along the nerve trunks may bring it into direct contact with the antitoxin.

However, recognizing the fact that other factors may have influenced the mortality, it is pertinent to note that in one series of 116 cases[23] which had received less than 20,000 units, the mortality was 78.4 per cent., while 41 cases observed under the same conditions, which had received more than 20,000 units, gave a mortality of 58.5 per cent. Also in another series of 108 cases receiving less than 20,000 units we find a mortality of 56.4 per cent., and 67 cases observed under comparable conditions, receiving more than 20,000 units, 31.3 per cent. was the mortality. These figures are given not as positive evidence of the effect of the antitoxin in treatment, but as tending to show that the serum in large amounts does influence the prognosis.

Method of Injecting Serum.—The opinions of different observers are at absolute variance as to the route which should be selected. On the basis that the method which will introduce with as little delay as possible a large amount of the antitoxin into the circulation, the intravenous method would seem to be the one of choice, and it has many adherents. Conclusions, however, drawn from the study of large numbers of cases have led certain authorities to advise strongly against the use of the intravenous method both because of the increased danger from anaphylaxis and because of the negligible effect of the antitoxin given in this way as compared with that given by other routes. By the intraspinal injection of the serum it is brought *en masse* to the vital region, the spinal cord, but unless there be some unexplained effect from the antitoxin thus introduced, as is the case under certain conditions with intraspinal injections of the arsenic compounds, it is difficult to understand why this method should give essentially more favorable results.

Sherrington[26] performed for the British Tetanus Commission a series of experiments on monkeys which should be given great weight. Ten[27] control monkeys and 10 receiving their antitoxin subcutaneously, all died. Of 12 treated intramuscularly, all died. Of 16 treated intravenously, 10 died, a mortality of 62.5 per cent. Of 18 treated intraspinally, 5 died, a mortality of 27.7 per cent. These experiments may also be analyzed, comparing the amount of infection with the number of units given. In the 12 monkeys[28] which were treated by intramuscular injections and which died without exception, there had been given a toxic dose of from 3.5 to 1.1 mgm. per kilo, and 2320 to 1250 units of antitoxin per kilo had been given. In the 18 experiments in which the antitoxin was given intraspinally the toxic dose was from 4.4 to 1.1 mgm. per kilo and the antitoxic from 2250 to 300 units, and of these monkeys 5 died, a mortality of 27.7 per cent.

Andrews[27] believes that different routes must be used in different cases, and reports 20 cases, 16 of which were treated intraspinally, with but 2 deaths. He recommends strongly the intraspinal use of the antitoxin as less liable to cause anaphylaxis and as giving the best clinical results. On the other hand, a most careful analysis made of 157 cases of acute tetanus occurring with the British Expeditionary Force made by Sir William Leishman and Major Smallman[23] seems to condemn both the intravenous and the intraspinal methods of introducing the antitetanic serum and to show that the intramuscular method of injection is less dangerous and gives distinctly better results. The cerebral subdural route for the injections has no advocates.

Anaphylactic Shock.—Fatal anaphylactic shock has been observed especially frequently after the intravenous injection, and mild reactions have not been rare, but the danger from these complications is so slight that if anaphylaxis does develop, the surgeon is free from criticism if precautions have been taken, while if he has performed any manipulation or operation without a prophylactic dose of the serum, he is open to great criticism should tetanus develop. If anaphylaxis be feared,

either from a previous reaction or from the prolonged interval after a previous injection, 5 c.c. of the antitetanic serum should be diluted with 50 c.c. of warm saline. One c.c. of this solution is injected intravenously and four minutes later 3 c.c. more are allowed to enter the veins. Then after two minutes 10 c.c., and 25 c.c. after another wait of two minutes, and finally, after another ten-minute interval, the remainder of the solution is allowed to run in. This amounts practically to the introduction into the circulation of 5 c.c. of the antitoxin diluted with salt solution during about thirty minutes. The experiments of Richet, Brodin, and Saint-Sisons indicate also that the sodium chlorid impregnated the nerve-cells and protected them from the anaphylactic poison.[19]

PROGNOSIS

In discussing the prophylactic use of the antitetanic serum there was universal agreement. In discussing the therapeutic use of this serum widely divergent opinions existed, but the *general impression prevails that large doses of the serum influence the prognosis.*

It should be mentioned that a combination of the antitetanic serum with a serum to prevent gas gangrene was tried by the B. E. F. The information obtained from the experimental data indicated that this combined serum might influence materially the incidence of both gas gangrene and tetanus. The time available for this experiment and the conditions under which it was tried were such that it is probable that no convincingly definite figures will be obtained, but it was the opinion of those qualified to observe that the incidence and character of both infections remained unaltered.[21]

In the cases of tetanus reported by the Surgeon-general as occurring in the Civil War we find:

	Total cases.	Recoveries.	Deaths.	Ratio mortality.
Head and neck	21	1	20	95.2 per cent.
Trunk	55	5	50	90.9 "
Upper extremity	157	18	119	86.8 "
Lower extremity	292	30	262	89.7 "
	505	54	451	

This table has particular interest because it shows a larger series of cases unaffected by any prophylactic treatment and representing unquestionably only the most frank and extreme clinical types, the atypical forms not having been described or having been unrecognized. Unquestionably, it far from represents the true number of cases of tetanus, and the mortality percentage is doubtless high, since atypical mild cases developing late were frequently not reported, and it is these cases which tend to recovery.

Prognosis Influenced by Length of Incubation Period.—The statistics of this time relative to the onset of the symptoms after injury are too indefinite to justify comparison with present-day series, but in the main the fact is brought out as by all published experience from the earliest times that the acute cases, those in which symptoms appear

in the first nine days, usually die, while those in which symptoms appear after nine days tend to recovery, the percentage of recoveries increasing in proportion to the delay in the appearance of the symptoms.

Failure to appreciate the importance of this interval between the time of the wound and the onset of symptoms has unquestionably caused many of the faulty conclusions which have been drawn in regard to different methods of treatment.

The average length of the incubation period of the cases of tetanus treated in England, as given by Major-General Sir David Bruce,[17] is most interesting and instructive. A striking relationship between incubation period and percentage mortality is shown by Table No. 2. The first series, with an average incubation period of 13.4 days, gives a mortality of 57.7 per cent. The fifth series, with an average incubation period of 67 days, gives a mortality of 19 per cent., and the eleventh series, with an incubation period of 54.8 days, gives a mortality of 26 per cent. Unquestionalby, various factors other than the tetanus infection influenced the mortality in these cases, but the relation between incubation period and prognosis is intimate.

The following was compiled by Major-General Sir David Bruce, to show mortality percentage and relation of period of incubation to mortality:

TABLE No. 2

Analyses.	Number of cases.	Recovered.	Died.	Mortality, per cent.	Average incubation period.
1. 1914–15.....	231	98	133	57.7	13.4
2. 1915–16.....	195	99	96	49.2	31.2
3. Aug.–Oct., 1916.....	200	127	73	36.5	30.6
4. Oct.–Dec., 1916.....	100	69	31	31.0	45.0
5. Dec., 1916–Mar., 1917..	100	81	19	19.0	67.0
6. Mar.–June, 1917.....	100	71	29	29.0	44.1
7. June–Sept., 1917.....	100	85	15	15.0	55.5
8. Sept.–Dec., 1917.....	100	84	16	16.0	46.9
9. Dec., 1917–Apr., 1918..	100	76	24	24.0	46.19
10. Apr.–Sept., 1918.....	100	74	26	26.0	68.5
11. Sept., 1918–Mar., 1919.	100	74	26	26.0	54.8

These analyses of the British Tetanus Committee also show that with better prophylactic treatment and with better surgery the percentage of cases increased in which the symptoms of tetanus were confined to local manifestations. The last two series of 100 cases each contained 27 such cases in which there were no deaths.

Effect of Type of Organism on Prognosis.—As bearing upon the prognosis and the incidence of tetanus bacillus in wounds, the results of Captain Tulloch's studies are important. In 23 cases not suffering clinically from tetanus, he isolated the tetanus bacillus and divided them into four types, 17 belonging to Type 1, 3 to Type 2, 2 to Type 3, and 1 to Type 4. Comparing these figures with those obtained from the analyses of 100 cases of clinical tetanus, he finds that while 74 per cent. of the cases with tetanus bacilli in the wounds belong to Type 1, only 41 per cent. are found with clinical tetanus. The mortality of these types in cases in which the special group was established is given as:

No. 1, 11 per cent.; No. 2, 25 per cent.; No. 3, 35 per cent.; No. 4, 0. If further examination of a larger series of cases confirms this ratio, it would seem that Type 1 was the most prevalent infection and accompanied by a relatively low mortality, while Types 2 and 3, though less frequent, are more virulent.

For the sake of comparing the antebellum cases with the results which have been obtained during the war, the statistics of Jacobson[29] are given, as they represent the experience of unselected cases. The average mortality of all acute cases of 83.1 per cent. and of all subacute cases as 43.6 per cent. is in striking contrast to the experience in the British home military hospitals, as well as the experience in the acute cases which were reported from the active hospitals in France, if due allowance is made in considering the mortality of the nature of the wounds and accompanying sepsis.

JACOBSON'S STATISTICS

Table I includes cases treated with antitoxin from other sources..... 144 cases
Table II includes cases treated with New York State Department of Health antitoxin..... 159 "
303 "

Table I		*Table II*
66 cases	treated by subcutaneous injections	42 cases
48 "	treated by injections into various structures	16 "
12 "	treated by intraspinal injections	.. "
16 "	treated by intramuscular injections	.. "
1 case	treated by intracerebral injections	1 case
1 "	treated by intravenous injections	..
144 cases		59 cases

Table I	Mortality	*Table II*	Mortality
93 acute cases.....	85.7 per cent.	29 acute cases.....	80.6 per cent.
44 subacute cases.....	34.9 "	21 subacute cases.....	52.4 "

Table I		Mortality
66 subcutaneous injections,	47 acute cases.....	82.6 per cent.
	18 subacute cases.....	22.2 "
48 cases, combination of intravenous, subcutaneous, intraneural, intracranial, and intraspinal injections,	30 acute cases.....	93 "
	14 subacute cases.....	50 "
Intraspinal injections, 12 cases,	7 acute.....	57 "
	3 subacute.....	

Table II		Mortality
Subcutaneous injections,	24 acute cases.....	79 per cent.
	16 subacute cases.....	43 "
Injections into several structures,	11 acute cases.....	81 "
	5 subacute cases.....	80 "

RÉSUMÉ

1. Tetanus bacilli may be present in every wound which is contaminated with the soil.

2. The presence of foreign bodies tends to increase the probability of infection by the tetanus bacillus because of the greater liability of contamination by the soil and because of the necrotic detritus in which these organisms flourish.

3. There are two essentials in the prophylactic treatment of tetanus:
   (*a*) Radical surgery to remove devitalized tissue and foreign material.
   (*b*) The creation and maintenance of a preventive immunity by injections of antitetanic serum.

4. *The incidence of clinical tetanus is controllable by the above means to an almost negligible percentage.*

5. The clinical types of tetanus are modified and the prognosis is materially improved by the prophylactic injections of the antitetanic serum.

6. The treatment of clinical cases of tetanus is unsatisfactory and uncertain, but in view of all experience the antitetanic serum should be given in large doses.

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CHAPTER VIII

ORGANIZATION AND ADMINISTRATION OF THE MEDICAL DEPARTMENT OF THE UNITED STATES ARMY IN WAR*

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FOREWORD

I have based my conception of the organization of the Medical Services in the field on that which obtained in large measure during the Great War. Upon this as a basis an attempt has been made to draw some conclusions and make some suggestions which only reflect personal opinion. The Medical Department must serve the troops in conformity with war plans and organization of fighting units. Rearrangements of these units, and changes in the science, practice, and theater of war will fundamentally change the medical service in conformity thereto. As these plans have not yet been published, it has been considered useful merely to describe the scenes amid which the medical sciences have lately been called to work, give a solution, and invite the interest of our medical men to add to or subtract from as they see fit. This foreword is necessary, as with a prewar organization which will not meet the present status of modern battles, and with a new organization in the making, we can only chronicle the facts in the last great war.

Among others, I am especially indebted to Colonels A. N. Stark, Chief Surgeon 1st American Army, A. E. F., and Charles Reynolds, Chief Surgeon 2d American Army, A. E. F., Colonels David S. Fairchild, M. C., Division Surgeon of the 42d Division, A. E. F., and Ralph S. Porter, M. C., Division Surgeon of the 26th Division, A. E. F.

THE ORGANIZATION AND ADMINISTRATION OF THE MEDICAL DEPARTMENT IN THE ZONE OF MILITARY OPERATIONS

Throughout the Great War the American Division consisted of about 28,000 men: two infantry brigades of two infantry regiments each, the commander of each a Brigadier-General. A regiment consisted of 3806 men, divided into three battalions of four companies each (256 men to a company), one headquarters company, one supply company, and one machine gun company (sixteen machine guns, mule-drawn).

The other Division elements were: One Field Artillery brigade, one regiment of Engineers, one Field Signal battalion, aëro units, and one Sanitary Train. The rest of the force was distributed as Division Headquarters, Train Headquarters, and Military Police, Ammunition Train, Supply Train, and Engineer Train.

The Division is the tactical unit of the Army, and, wherever possible, acts as a unit. It must be prepared not only for concerted action with other divisions but also to act alone. For this reason it contains representatives of all arms of the service in relative numbers sufficient to meet the ordinary emergencies of battle, whether in a war of position or one of movement.

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The Commander of the Division is a Major-General who has under him a Chief of Staff and his assistants—referred to as G-1, G-2, and

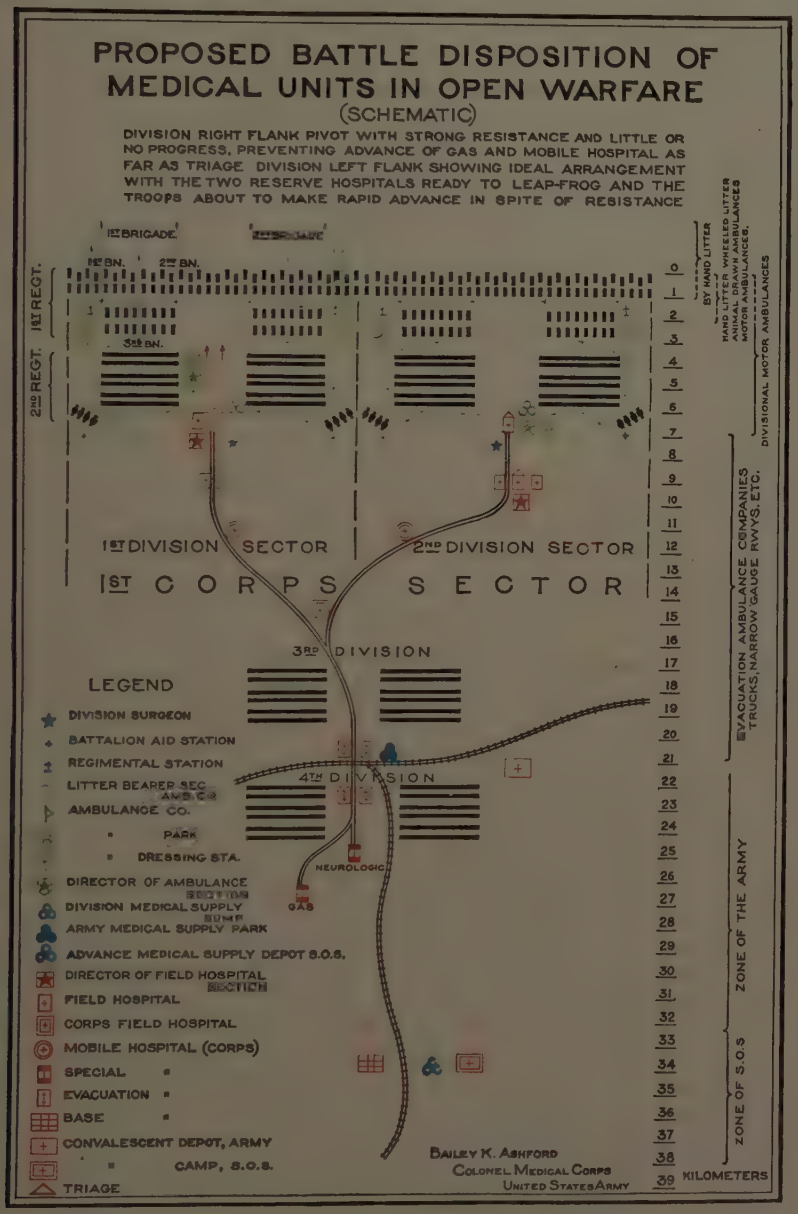

FIG. 9.

G-3—who supervise respectively all matters of administration and supply, military intelligence, and military operations, forming the General Staff Council which, under the Commanding General, directs all mili-

tary matters in the Division. On the General's Staff are also an Adjutant, an Inspector, a Judge-Advocate, a Chief of Engineers, a Motor Transport Officer, and the Chiefs of the Quartermaster, Medical, and Ordnance Departments, and of the Signal Corps of the Division. All these are his technical advisers, and under the Chief of Staff their activities are co-ordinated to the end that the military object in view, that of defeating the enemy, may best be subserved. The will of the Commanding General, however, is final, and while his decisions are based on thorough information from his subordinates, the military end in view is paramount to all.

The Corps normally consisted of five Divisions, four combat and one replacement.

The chief function of the Corps Commander is the proper employment of his reserves. It is impossible to furnish every Division with all that they *may* need; only the elements are provided which a Division in ordinary campaign will *probably* need. Extra elements which may be needed for special situations at important crises are held in reserve by the Corps. This is an important function which vitally affects the divisional medical service, as will be seen.

The Army.—An army is composed of such number of troops as may be needed to control the military situation in a large section of territory vital to the general national military plan as outlined by the Commanding General. It rarely consists of more than five Corps in our Army, but naturally this number cannot be fixed. It also has special troops.

Organization of the Medical Department of the Division

There are three elements fairly well differentiated by their function in every Division:

1. The medical service of the combat organization (the "regimental service"), "attached sanitary troops."
2. The evacuation service (the "ambulance service").
3. The emergency hospital service (the "field hospital service").

The Regimental Medical Service.—A Regiment has seven Medical Officers, one Major, and to each battalion two Captains or First Lieutenants. In addition, one or two Dental Officers are assigned as needed. The Regimental Detachment consists of 48 enlisted men. This gives a Battalion Medical Service of 2 officers, 1 sergeant, and 12 privates for 1000 fighting men. This number is sufficient in campaign only during inaction or relatively mild activity. In any serious engagement this nucleus requires heavy reinforcement.

In practically all Divisions during the late war from 4 to 12 enlisted men of each fighting company were detailed as litter bearers. These men were distinguished by an armlet and usually by the letters "L. B.," and were subject to the call of the Battalion Surgeon for litter bearing only. When not so utilized they were available for the fighting line, as at all times they bore arms and, it is needless to say, were not immunized by the Geneva cross. Where conditions required the use of litter bear-

ers as above described, it was a general custom to detail 2 enlisted men of the Battalion Medical Detachment to each company to remain at all times on the firing-line as dressers and First Aid men, thus leaving 1 sergeant and 4 men to the Battalion Medical Officer and his assistant.

The Functioning of the Regimental Service.—This Regimental Detachment is the working force and its officers the sole representatives of the medical profession constantly at the elbow of the fighting man. There is nothing too good for the regimental medical service. The enlisted men must be carefully picked, particularly for their courage, good judgment, fortitude, and physical development. Their training must be practical for what they have to do.

If care should be exercised in the selection of the enlisted man, how much more necessary is it to select the right medical officers. They must not only represent an "ancient and honorable profession on the field of battle," as doctors of medicine and surgery, but they must also be possessed of a working knowledge of military matters. Theoretically, the military commander furnishes this knowledge and its application. Practically, however, he expects every unit commander under him to make himself responsible for the men of that unit. As medical officers of the regiment are not only responsible for their own detachments but also for an ever-swelling tide of helpless wounded whom it is necessary to disentangle promptly from the fighting mass, it behooves them to know details of terrain exposed to fire, strategic moves, the position and objective of troops, and, above all, the maze of routes of evacuation embodied in maps. They should know woodcraft, the habits of the enemy as to shelling, the improvisation of cover, and many other things not taught in the medical sciences.

But of all the traits a Battalion Surgeon should possess, nothing is more vital than that he should have the ability to win the confidence and respect of officers and men. The power for character analysis on the part of the soldier—and particularly of the American soldier—is extremely penetrating. He is apt to know his officers' virtues and failings better than those officers themselves know them, and when once he concludes that his leaders are worthy to follow he is not niggardly in his devotion.

The rapid and systematic recovery from the field, the emergency treatment, and the prompt evacuation of wounded are duties of a Battalion Surgeon known to all. But there are other duties, also known, but too little considered, which must be added:

1. Ability to make a rapid general estimate of the nature and extent of a man's injuries and place it in a few concise words on the diagnosis tag. This will prevent the wounded man from being held up on the route back to the unit to which he should go for definite treatment.

2. Ability to change a plan of action from one moment to another as new phases develop from the military situation, and to work successfully despite lack of proper equipment.

3. Ability to realize that in addition to his duty to humanity he is applying the medical sciences to the purpose of war, which is to *win*,

and that every man salvaged to fight again is a replacement. It is of equal importance for the morale of a fighting unit that the men should confidently rely on an efficient Medical Department for their first aid and prompt evacuation. Thus, wounded men will be sent promptly to the rear, properly prepared for treatment, and with as much definite information as possible concerning their condition.

No consideration can be given here to the prevention of disease, but an intimate knowledge of all that pertains thereto is an essential in the make-up of an ideal Battalion Surgeon. In other words, he is the representative at the front of all phases of our art and science reduced to their simplest and most practical terms. It will be seen, therefore, that a well-educated, high-spirited young man in perfect physical condition, with common sense, a sense of humor, and the ability to make friends, is the man needed best to represent at the front the science we profess.

The Battalion Surgeon is quite the most privileged of our profession in time of war. He is by no means a mere emergency surgeon. Upon his decision as to when, where, and how to send a wounded man, the ability to accomplish the movement rapidly, easily and safely, and the forethought to send with the man definite information concerning his condition, depend in large part the fate of a man, the happiness of a home, the useful life of a citizen, and a replacement for the army. For successful surgery in modern warfare does *not* begin on the operating table, but out *at the front*. The surgeon who deprecates military art and science and neglects to inform himself thereon, thinking that the profession he learned to apply in civil life can always be applied in the same manner in war, does himself a great injustice, and still greater to the unfortunate soldier.

If there is one lesson which this war has taught us it is that the success of a surgical operation depends on the rapidity and freedom from the precipitating causes of shock to which a wounded man is subjected en route to the operating table. What happens to the man from the time when he falls to the time when he goes to the operating table is one of the chief factors in his chances for recovery. Hence, the operating surgeon must look with more than ordinary interest on what is happening to his prospective patients "up front." It is not hard for him to get the battalion surgeon's co-operation if he makes himself master of the latter's problems; and to do this he must know something more than the amenities of camp life and the ideal disposition of medical units in the field.

Regular Battle Stations

Stabilized Warfare (Trench Warfare).—In inactive sectors the line is usually thin and long, from 4 to 16 kilometers, and there are two or three regiments in the front and one or two in reserve. On the defensive a relatively small number of troops is placed in the trenches and a relatively large number is held in reserve where they are not subjected to the strain of trench life, but are near by in case of need. A battle

front consists of a number of positions or zones with unoccupied zones between. Each of these positions consists of at least one and almost invariably several lines of combat groups, usually connected by continuous or nearly continuous trenches parallel to the front—the so-called parallels—the successive lines being connected by the necessary communication trenches running at right angles thereto.

The main or front battle position is usually occupied by a number of complete battalions, each having certain companies in the principal parallel and others in support. Detachments from these front line battalions are usually sent forward to lightly hold the outpost position. The remaining troops are held in dugouts or under natural shelter in the rear, ready to reinforce the first line battalions or to counter-attack in case of need. The principal reliance of the defense is in the machine-guns properly disposed in sufficient numbers and supported and protected by infantry.

The front line units are relieved from time to time by fresh units from the reserves. The term "serving in the trenches" applied by the soldier meant service in the trenches of the outpost or battle positions.

The relief of the front line battalion now takes place, a reserve battalion taking the front position, and the front line battalion retiring. Normally it amounted to six to eight days in the trenches and ten to twelve in the rear. It was during this relief if discovered by the enemy —usually at night—that a flare-up of enemy activity could be expected.

The trenches, ideally, were deeper than the tallest man; up to 8 feet wide; revetted if necessary; changing direction every few paces, terminating at their lowest point in a V; interrupted by sump holes for drainage, and floored by a duckboard path resting on a skeleton support frame. Along the sides were strung telephone wires, and at intervals in the principal and support parallels of the battle position were the entrances of the famous "dugouts" or "abris," defended against gas attack by two tight-fitting curtains, one 6 to 9 feet from the other, and falling by a touch at the sound of a gas alarm.

Dugouts, preferably, should have 18 feet of overhead cover, but this is rarely seen. Usually 10 feet protection against 75's and 155's, the fire to which these dugouts will usually be subjected, were provided. Heat is supplied by coke braziers, light by miners' lamps or candles; at times by electric lights (in old, quiet positions) or carbide lamps. Smoke, fresh excavations, and movement of groups of men, even within trenches, are reduced to a minimum on account of direct and indirect enemy observation from their trenches or their balloons or avions. The entire area, with its maze of trenches, is plotted from aërial photographs by their artillery, and the slightest unusual movement is signaled by balloon, bringing a well-aimed shell.

To repel an attack in force the stand is made in the principal and support parallels of the battle position. To attack, the assaulting troops are secretly massed as far forward as concealment and safety permit, and go over the top at the hour previously determined by conditions, as "H hour."

Activity in a trench sector draws hostile fire, which falls generally among the reserves or cuts temporarily the communication to the rear by a curtain of rapidly falling shells. Hence, one of the most dangerous points in active times is to the rear of the support parallel. The distance from the most advanced opposing line varies from 250 to 1000 yards—usually being nearer 250 than 1000. Often it was much less than 250.

The **battalion aid post** was situated as near battalion headquarters as possible, generally near but not properly at the junction of communicating trenches with the flanks of the battalion position. This dug-out, like all others, had but two sizes of chambers: one the ordinary 1 x 2 meters, and the other the "galérie majeure," 2 x 2 meters. Water and food are usually carried up from the support or the rear thereof; in old sectors well established kitchens may be found in the support, and cement water tanks filled by pipe line. When food is carried up it is in marmites or large thermos cans holding sixteen rations. It is at mealtimes that shelling of the communication trenches is apt to take place. By learning the habits of their close neighbors the enemy, each side, manages to inflict from five to twenty-five casualties a day. These periods of relative inactivity of siege were referred to by the English soldiers as "peace times," a term still applied to their noisy line toward Ypres, where for a long period seventy to ninety casualties a day were the rule, generally due to sniping and grenade or high-explosive shell fragments.

Usually, with a gas-curtained vestibule 9 feet long and a descent of 30 degrees, a reception and dressing room, a ward with from ten to twenty-five bunks for seriously wounded, and a room for the medical officers and the men on duty, a Battalion Surgeon could feel satisfied that the essentials of the Medical Department dug-out had been provided. The longer his stay, the more he should have improved his dug-out by drainage, boarding of walls and their whitewashing, floors, etc. To recount the ingenious contrivances of men obliged to live underground, to adorn and provide comfort—even to provide diversion in these contracted holes—would require a separate chapter.

First aid was provided for by detailing two Medical Department privates 1st class or privates as First Aid men or dressers to each company in the line. There they remained, and established what some called an "advance aid post." First aid consisted mainly in the application of the Thomas splint and dressings. The men were usually littered back by line soldiers detailed as heretofore stated. From one-half to one hour from the time a man is hit until he arrives at a Battalion Aid Station is not excessive, and often for military reasons or from prudence, when violent shelling was taking place, the wounded could not be moved until a propitious moment—often at nightfall. As a matter of fact, nightfall was often the signal for renewed activity on the part of the enemy, and most wounds occurred at such a time. When a sector became active it was generally connected with raids on an advance in force. In a small attack one of the battalion surgeons

established a true advance aid post in the trenches, went over the top with the battalion commander in the third wave, and, in event of many casualties, established the new Battalion Aid Post in case of a definite advance in the first or second line of enemy works captured. In raids of considerable size one of the battalion surgeons went over also, more to give a sense of security to the men than for any other reason. In small raids one or two privates of the Medical Department accompanied the party. In these passages of "No Man's land" splinting and dressing were done *in situ* whenever possible, but in rapid thrusts with withdrawal, men might be left between the lines until darkness came on. This was not the rule, however. The individual bravery of the American soldier brought wounded men in under cover of our lines in broad daylight—at times veritable feats of the Trojan age brought down to our day.

The Equipment of a Battalion Aid Station.—The medical equipment weighs 1900 pounds and has a bulk of 106 cubic feet. It is to be carried on a four-wheeled, rubber-tired spring wagon, ball-bearing, and cut-under. It is to be drawn by four horses trained to carry pack saddles and with four pack equipments, which can carry all this material in case the wagon cannot be carried over the ground. The wagon has collapsible seats, making possible its return from the front carrying patients, twelve extra litters packed on its sides, and so constructed as to allow it to be hitched to the rear of a truck as trailer in case of accident to the horses. Unfortunately, this wagon was not available during the war, and only a one-mule cart carrying some 500 pounds was provided. It is intended that the wagon as described shall replace the old unwieldy and insufficient medical cart, and when furnished the animal-drawn Ambulance Company and Field Hospital will be substituted by motorized units.

The front dressings were first used by the French in place of the first-aid packet devised for bullet wounds. They are made dressings, voluminous enough actually to cover a lacerated wound from high-explosive shell, and consist of cotton-filled gauze pads with pins and bandage, all sterilized. They are made up in three sizes and are a tremendous improvement over the easily soiled, tiny, first-aid package.

The combat equipment of a battalion is always kept replenished from the divisional Medical Supply Depot.

The **Regimental Aid Station,** needful in certain kinds of warfare, in the modern battles of Europe usually fulfilled but a shadow of its former mission, and was being more and more relegated to the position of a headquarters for the Regimental Surgeon and a local infirmary for the sick of regimental headquarters. The chief reason for its desuetude, however, lies in the impropriety of interposing an unnecessary block in the rapid evacuation of wounded to their places of definite treatment.

The evacuation of wounded in a quiet trench sector is always performed by regimental personnel as far as the Battalion Aid Station, as has been recounted. In this war the number of bearers was changed

by common practice from 2 to 4, and the litter carried not at arm's length, but by resting the four handles on the shoulders of the bearers. Carrying by two is not so easy in trenches—at best a difficult undertaking from slippery paths and long, winding trenches. The entire army adopted the more feasible plan of carrying by four.

A great variety of litters have been invented, most of them by those who do not have to carry them. The French had, here and there, the

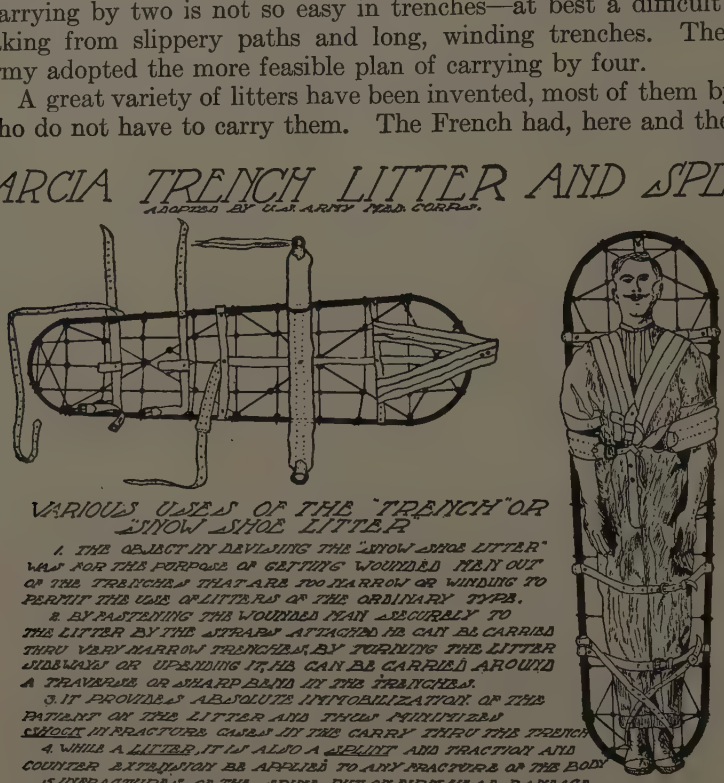
GARCIA TRENCH LITTER AND SPLINT
ADOPTED BY U.S. ARMY MED. CORPS.
VARIOUS USES OF THE "TRENCH" OR "SNOW SHOE LITTER
1. THE OBJECT IN DEVISING THE "SNOW SHOE LITTER" WAS FOR THE PURPOSE OF GETTING WOUNDED MEN OUT OF THE TRENCHES THAT ARE TOO NARROW OR WINDING TO PERMIT THE USE OF LITTERS OF THE ORDINARY TYPE.
2. BY FASTENING THE WOUNDED MAN SECURELY TO THE LITTER BY THE STRAPS ATTACHED HE CAN BE CARRIED THRU VERY NARROW TRENCHES BY TURNING THE LITTER SIDEWAYS OR UPENDING IT, HE CAN BE CARRIED AROUND A TRAVERSE OR SHARP BEND IN THE TRENCHES.
3. IT PROVIDES ABSOLUTE IMMOBILIZATION OF THE PATIENT ON THE LITTER AND THUS MINIMIZES SHOCK IN FRACTURE CASES IN THE CARRY THRU THE TRENCH
4. WHILE A LITTER, IT IS ALSO A SPLINT AND TRACTION AND COUNTER EXTENSION BE APPLIED TO ANY FRACTURE OF THE BODY
5. IN FRACTURES OF THE SPINE, PUT ON FIRM HEAD BANDAGE WITH TAILS OF BANDAGE EXTENDING FROM BEHIND EACH EAR AND TIED TO TOP OF LITTER HOLDING HEAD AND NECK RIGID.
6. FRACTURES OF ARM AND FOREARM. PUT UP FRACTURED ARM IN WIRE GAUZE OR THIN BOARD SPLINT. LOOP BANDAGE UNDER ARM PIT AND TIE TO UPPER END OF LITTER. LOOP BANDAGE AROUND WRIST AND TIE TO SIDE OF LITTER BELOW HAND AND TWIST BANDAGE FOR TRACTION.
7. THIGH AND LEG. PUT UP FRACTURED LIMB IN WIRE GAUZE OR BOARD SPLINT. CROTCH STRAP GIVES COUNTER EXTENSION. TRACTION PROVIDED BY BANDAGE LOOPED ABOUT ANKLE, TIED TO END OF LITTER AND TWISTED FOR TRACTION.
8. WHEN FRACTURE CASE HAS BEEN CARRIED TO AID STATION WHERE AN AMBULANCE IS AVAILABLE HE CAN BE REMOVED FROM THE SNOW SHOE LITTER AND PUT UP IN A THOMAS OR OTHER SPLINT.
9. WHEN THE FRENCH WHEELED LITTER IS USED TWO PATIENTS CAN BE CARRIED BY SWINGING TWO SNOW SHOE LITTERS ON IT.
10. IF LOADED INTO AN AMBULANCE THE SNOW SHOE LITTER SHOULD BE PLACED ON A U.S. ARMY LITTER.
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FIG. 10.

hammock swung on a bamboo pole for the rough and perilous carry over "No Man's Land," and from the fire trench to the aid station; but our men always preferred our old litter. The only trench litter which so far has survived the experimental stage is the snowshoe litter of the American Army. This is merely an elliptic frame of metal tubing on which is swung a rope-woven net upon which the patient lies and to which he is securely strapped. He cannot fall from it and it can be

turned in any position to round corners, let men pass who are going in the other direction, etc.; moreover, it is light (Fig. 10).

On arrival at the aid station the patient is rapidly inspected, the worst of the macroscopic dirt removed, with any protruding bone unattached by periosteum, or a plainly visible projectile, and an approximate estimate is made of his injury. This is done, or should be done, in a recumbent case, on a shock table, after the administration, *if necessary*, of a hypodermic dose of $\frac{1}{4}$ grain of morphin.

The patient is next given a preventive dose of antitetanic serum, his wound dressed, and a splint applied if necessary. He is then turned over to an ambulance company litter bearer section, with his diagnosis tag duly inscribed. It depends entirely on the amount of activity in the sector how carefully and systematically all this work is performed; but there are at least *six things* which must be done if humanly possible.

1. **The Prevention of Shock.**—If a Battalion Surgeon can do no more than prevent shock and evacuate his patients, he will, in the main, have accomplished his mission. The following improvisation of a shock table, made by resting a litter on a litter-stand or "saw-horse," was one of many similar methods taught and used extensively in all the allied armies (Fig. 11).

Some were more varied in their application of the principles stated, the chief divergence being in the manner of conducting heat to the patient and the means of retaining it. For the first, hot air from the lamp (oil or alcohol) was conducted up through a stove-pipe, and then at right angles throughout the length of the litter or table, the pipe at this portion being split over its entire length and encased in folds of blanket, or boxed. The cover used over the patient was a hood, usually made of sheets of cheap, fluted cardboard, which were rapidly arched and bound together by paper fasteners on a light wooden frame. In hospitals these hoods were apt to be of heavy canvas on light wire frames, and heat was provided by a battery of electric lights both within the hood and under the litter or canvas bed of the shock table. Some of these hoods had windows capable of being opened and closed, through which the pulse could be felt and dressings observed for hemorrhage.

The prevention of shock is accountable for a goodly share in the reduction of mortality at the Field and Evacuation Hospitals. Whatever may be the scientific mechanism by which shock is produced, previous exhaustion—moral, mental, and physical—cold, and pain are the outstanding factors in bringing it about; and the greatest of these is chilling.

Shock is not usually seen at the Battalion Aid Station, save in the case of greatly delayed wounded who have lain out on the field. The collapse due to excessively severe wounds taking place there is due to the anatomic location and extent of the injury. Shock due to hemorrhage was considered separately by many. As Crile put it, in his talks to our officers at the front, a soldier's vitality being quoted at

100 per cent., there is a certain percentage of this available to expend for combating shock. Below this margin the man's chances for life become less and less, and there comes a point, best interpreted by the fall in blood-pressure, when he must inevitably die.

The great basic fact to be remembered in preventing shock is that the wound is merely the detonator of an already prepared charge. The

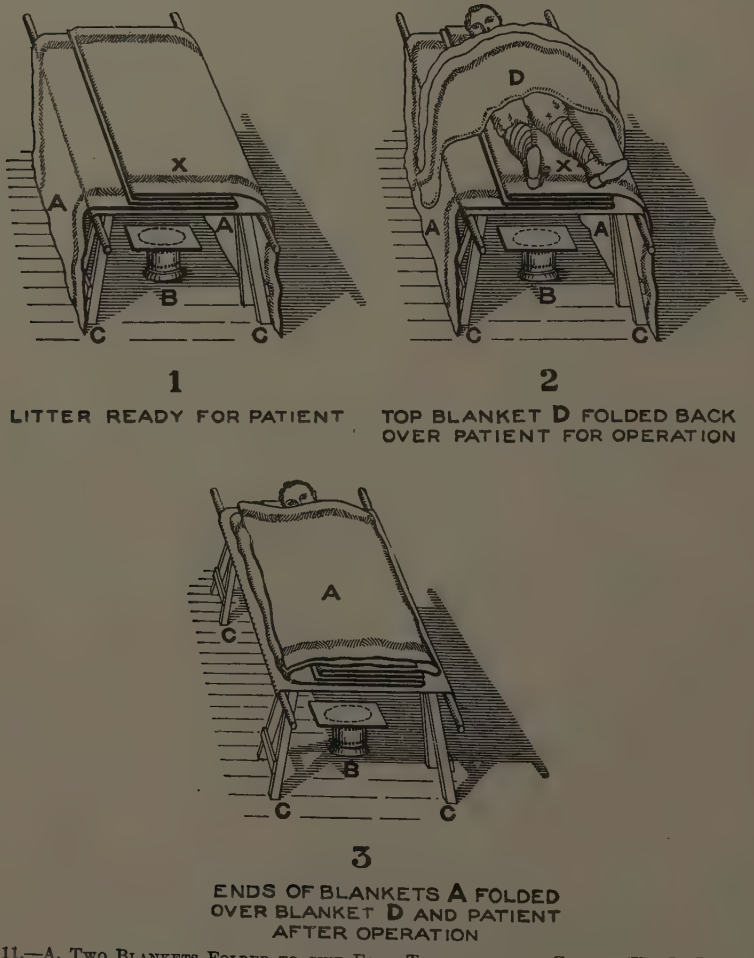


FIG. 11.—A, TWO BLANKETS FOLDED TO GIVE FOUR THICKNESSES IN CENTER (X); B, PRIMUS OIL STOVE WITH METAL PLATE; C, TWO TRESTLES TO SUPPORT LITTER; D, TOP BLANKET.

cold, exhaustion, lack of food, anxiety, and other violent emotions—rage, fear, worry, homesickness—and, above all, loss of sleep, each claim a few per cent. of that which may be necessary to cover the margin of safety. All of these conditions, plus pain and hemorrhage, lower the alkalinity of the blood, and the greater the acidosis, the graver the state of the patient. Hence hot and alkaline drinks are

recommended, but it should never be forgotten that fluid must be given in abundance and that water will not necessarily have to be alkalinized.

It will thus be seen that there is more than an esthetic reason for making our men comfortable in mind and body and "keeping up their morale." All the comforts we can reasonably give them on the field of battle—and they are pitifully few—are simply going to prevent the last ounce of fuel from being burned before the soldier comes to the supreme test of battle. It is this condition of shock and pre-shock that, more than all else, requires a trained medical personnel for the ambulance evacuation. Not that mistakes are not made and men pushed on when they should be allowed to take chances where they lie; not that the wrong patient, the wrong road, or the wrong driver is not, at times, chosen to hurry to the rear: but that a trained personnel will make far fewer such blunders, and that the responsibility falls on a professional class which realizes its whole duty all the time.

2. **Arrest of Hemorrhage.**—By the time the wounded man is within reach of the surgeon hemorrhage is not usually a problem of any great magnitude—contrary to the popular idea. Few arteries are tied in an aid station. There is greater danger from the unjustifiable application of a tourniquet than from its neglect. This danger, of course, has to do with the devitalization of tissue—the predisposing cause of infections, especially those producing gas gangrene. There are times when the tourniquet must be used, but after a brief period of tightening it may be loosened, and carriers instructed to look out for recurrent hemorrhage en route and to tighten the tourniquet when needful. An excellent method is to catch an artery firmly and transport the patient with the artery forceps in place protected by a voluminous bandage. Usually, a well-applied bandage itself will resolve most cases of hemorrhage.

3. **Proper Dressing.**—*Wounds should not be touched by the hands if possible to avoid it.* The human "carrier" of the Streptococcus hemolyticus will sow in a wound the most feared micro-organism in military surgery. "Knife-and-fork" methods are imperative. Dressing forceps with their points in a cresol solution, sterilized sponges in an enameled jar, the application of iodin, and the application of a well-fitting, abundant dressing is usually enough to prevent gross contamination.

4. **Splinting.**—The principle of the Thomas splint—extension by a separating force, and counterextension by resistance offered through the bony framework of the patient, supporting the light, rigid apparatus—should be applied to all fractures of the extremities to which it is applicable. For all gunshot fractures of the thigh and upper third of the tibia this splint should be used. The English made a drill of the proper application of the Thomas splint and taught it with a view to making its adjustment by Medical Department personnel automatic, so that it could be properly fitted under all conditions of excitement, fear, and darkness. They did not consider a man trained to put on this splint

unless he could accomplish it in five minutes, and this facility was usually attained by four days of consecutive practice.

The Thomas splint should be used not only for fractures but also for large flesh wounds involving vessels to secure immobility. It cannot be used when the wound involves a part of the buttock or perineum which the ring must girdle. It can often and, if possible, should be applied where the soldier falls. Usually, however, it is adjusted in the Advance Aid or Battalion Aid Station. The limbs which have been saved and the cases of fatal shock that have been averted through the arrest of pain by this apparatus are incalculable.

5. **The Injection of a Dose of 1500 Prophylactic Units of Antitetanic Serum.**—This measure should be applied at the aid station, but frequently military operations make it impossible there. By common custom a cross was painted in iodin on the man's forehead when the injection had been made.

6. **The Inscription of the Diagnosis Tag.**—This tag labels the man, and if date, name, organization, and the nature and severity of his wound, or other cause for evacuation, are clearly stated, and the fact of his having had antitetanic serum and morphin, with the dose of the latter, is expressed, data of incalculable value will have been collected. It is for the purpose of easing the minds of the man's family, establishing the responsibility of the government in the case, and for other perfectly palpable and practical reasons. There are times when even inscription cannot be made at battalion stations; but it must be done at the dressing station or Field Hospital.

The Battalion Surgeon.—The fascinating work of a Battalion Aid Station cannot be dismissed in a few words. Here there is time only for the big, vital things.

During great activity patients must be rapidly sent to the rear. Time is the greatest element to be considered, as much from the military as from the humanitarian and surgical point of view. This is no place to keep wounded men, save those *in extremis* or in profound shock. Trifling wounds should be dressed and the men sent back to the front. It requires a clear head and plenty of character to preserve order and system at a Battalion Aid Station. One of the best preventives of disorder is to impose relative silence. Only the Battalion Surgeon who has lived the life of the men and has been in and about their posts of duty, always preserving the dignity of his calling, but binding the men to him in affection by his constant solicitude for their well-being, can handle them in excited moments. It is not enough to mouth platitudes. The men like a dash of humor and like to feel that "their doctor" is a "human bein'." They know that they cannot deceive him, but they also know that he will *always* get in contact with them when they really need him, wherever they may be. Thus at the last analysis, when things are reduced to their simplest expression, it is the old, old story of the doctor and his patient whom we used to know in civil life.

The **Regimental Surgeon** co-ordinates the work of his three battalion

posts and supervises them all. He provides reinforcements, from the personnel he has at hand or from the other battalion posts, for any individual post that is hard pressed. Through the Regimental Commander he keeps advised of the military situation at all times. His responsibility for actual evacuation rearward ceases when the wounded reach the Battalion Aid Post. While the burden for maintaining contact between the ambulance companies and his aid posts lies largely with the Director of Ambulance Companies, he must seek in every way to preserve that contact. Upon him devolves the responsibility for supplies, and he must arrange for their automatic delivery at aid stations, every litter squad carrying back from the ambulance head replacement for what equipment they take down, plus replenishment of dress-

FIG. 12.—SINGLE-DECK WHEEL LITTER, AMERICAN ARMY, FOLLOWED BY FRENCH WHEEL LITTER ON SHELLED ROAD TOO EXPOSED FOR TRUCKS AND AMBULANCES, 32D DIVISION, SEPTEMBER 14, 1918.

ings, etc. He has full charge of sanitation and is the source of sanitary measures recommended. In short, upon this one officer rests the full responsibility for the work of the medical service of the regiment. At least 2 of his 7 privates are runners, and a bicycle is a real necessity.

In the evacuation of the wounded from Battalion Aid Posts to the Ambulance Head many bearers are needed. It is believed that the experience of most medical officers in the late war leads to the conclusion that this litter bearing should be performed by a squad supervised by an officer from the Ambulance Company. A Litter Bearer Section of an Ambulance Company, under its own officer, therefore works in co-operation with the battalion and regimental medical officers. Such officer at the same time preserves liaison between the

Battalion Aid Post and the Ambulance Company for supplies as well as for facility of evacuation. It is unusual that more than three round trips of this kind can be made in twenty-four hours by the same squad. A solution of the difficulty was often provided—again thanks to the daring and energy of our Ambulance Company personnel—by running up to the Battalion Aid Station with light ambulances, and thus furnishing mechanical litter-bearers who were able to carry 3 recumbent

FIG. 13.—DOUBLE-DECKED WHEEL LITTER RECENTLY ADOPTED BY THE AMERICAN ARMY; ADOPTED FROM ONE DEVISED BY COLONEL LEON C. GARCIA, M. C., AND USED IN ACTION WITH GREAT SUCCESS.

patients in far less time than would be necessary to bring one man in with 4, and often with relays of 8 or 12 bearers. We lost ambulances in that way, but by working in bad sectors chiefly at night the loss was justified by the saving in lives, in time and energy, and in workers otherwise eliminated from the places where they were most needed.

In this section of the route to the rear the ground is best covered by wheeled litters, should ambulances be not available at the Aid Station. Two-wheeled litters now proposed for the combat equipment are fold-

ing, light, double-decked, and can be used for returning medical supplies to the front. In the wider communicating trenches to the rear a wheeled litter will fit and is a God-send to the weary bearer. As a matter of fact, by night habitually, and occasionally by day, bearers will take to paths or roads on the surface rather than slip and slide through a winding trench. At every 1000 yards a relay station to the rear should be provided, with a squad of 4 on duty at all times, and a few necessities for First Aid, and hot liquids. The light railways supplying the front with ammunition were also used to transfer patients to the rear (Fig. 14).

The Battalion Aid Station in a War of Movement.—In open warfare everything is cut down to secure mobility. Here the dream of a dug-out, of a protected, relatively well-organized, well-equipped, fixed point at which wounded can be prepared for their journey to the rear,

FIG. 14.—UTILIZATION OF LIGHT RAILWAY FOR TRANSPORTATION OF WOUNDED.
(Mobile Hospital Unit 39, Aulnois, July 1, 1918.)

has vanished. Pressing on through mud, in blistering heat or searching cold, each heavily laden soldier must carry his equipment on his person. The roads are jammed, provisions are far in the rear, hopelessly separated from the tired, hungry troops. As the scene of their battle approaches, movement is by night. The men go in silence, struggling over villainous paths, at times over slippery roads, slushing through pools of water, or sinking over their shoe-tops in mud; at times in a cloud of suffocating dust; at other times struggling through heavy sand. The darkness is complete. No lights are allowed. In muddy weather, with poor and insufficient roads, the section of the column devoted to the trains presents a scene never to be forgotten. Ammunition, food, medical supplies, and men are welded into a struggling mass which crawls along with many an exasperating jam and enforced halt. In rainy

weather large trucks are apt to slide into a ditch, thus blocking traffic. Many a time an ambulance company, a field hospital, precious supplies, are firmly wedged in among these elements, and hours are consumed in covering a mile or so. Not rarely, although not strictly part of the military program, the enemy decides to shell the road, or avions bomb it. The result must be left to the imagination. This picture is drawn in order to demonstrate to what extremities a command may be put to transport its material. To those who would exclaim, "Why didn't they have this or that?" let us refer them to an all-too-frequent picture, impossible to overdraw, useless to try to avoid.

The men reach their jumping-off place and bivouac perhaps in a wood. In spite of best endeavor, their location may be suspected or

FIG. 15.—WALKING WOUNDED NEAR LA CHALADE, ARDENNES FOREST, OCTOBER 2, 1918.

known, and violent shelling may take place. The attack is ordered, and the leading battalion moves out. The Battalion Medical Detachment, less 2 men with each company as dressers, closely follows the troops. When casualties begin to occur the Battalion Surgeon selects a culvert or wooded ravine, the stump of a deserted house, a shell hole —any place he can get to lay his wounded. Of their own instinct wounded men tend to drift to the rear along certain lines (Fig. 15). It is well for the Battalion Surgeon to know these tendencies. It is absolutely indispensable that he know something of the map and of the intentions of his commander if he is to render the best service. A medical cart of the old type is generally far in the rear. The men have stuffed gunny-sacks full of dressings, and carry other supplies on their litters. The

medical belt did not prove a success in this war. A pouch is better. Better still is a bag.

Here is where first aid must be well understood by everyone, for ninety-nine times out of a hundred the man himself has no doctor at hand to tell him what to do. In a short time, an hour or more—or less—everything must be hastily dumped back into the bags and the detachment press forward to re-establish again near or among the troops, leaving behind a private to care for the wounded, and despatching a runner to get the Ambulance Company to pick them up. In spite of all, diagnosis tags are written, dressings well applied, wounded men collected in little bunches, hot liquids furnished, and even antitetanic serum and morphin given; and all this with the air full of metal and the put—put—put of machine guns, the deafening explosion of shells, and the occasional wounding or death of one of the little medical group or their already wounded patients. Notwithstanding even darkness, dirt, and confusion the dressings are applied. Light is simply not tolerated, and, as a matter of fact, the death sentence, inflicted by the enemy, is the price usually paid for such temerity as the lighting of a match or the flashing of an electric lamp. How can a medical officer in the rear who knows these scenes complain of the poor dressings or lack of care of wounded on the part of the Battalion Surgeon?

The outstanding problem now becomes simple in expression, but fearful in reality. The Ambulance Company must find these hidden nests of wounded, and get them to the rear. Liaison and rapid evacuation have taken precedence over everything else. In the excitement and vigor of the attack into which every fighting man has compressed every ounce of his best, no one has any time to give military advice to a medical detachment. Every nerve is being strained to bring up supplies and to press forward, and it is against that eager flood that the wounded must go. Here the Regimental Surgeon must be extremely active. He has quite enough to do in keeping track of his collecting points for wounded and in supplying his battalion detachments. With him should be an officer of an ambulance company with a litter bearer group, as stated. Only in this way, by runners between Battalion Aid Posts, Regimental Surgeons, and the ambulance head, can liaison be preserved—and liaison is vital. Once contact is lost between the ambulance company and the battalion aid posts, the price in suffering is heavy. Under such circumstances delay in reaching the Evacuation Hospital far in the rear gives infectious processes such headway that simple surgical procedures become formidable ones, if, indeed, profound and fatal shock does not stay the surgeon's hand entirely.

The Evacuation Service.—The basis for this service is the Ambulance Company, of which there are four in each Division; during this war one animal-drawn and three motorized. Now all ambulances and field hospital companies are motorized. The four companies form the Ambulance Section of the Sanitary Train, which with the four Field Hospital Companies (the Field Hospital Section) are commanded, under the Division Surgeon, by a Lieutenant-Colonel of the Medical Corps,

the Commanding Officer of the Sanitary Train. The Field Hospital and Ambulance Sections are commanded each by a Major, Medical Corps, Director of Ambulance Companies, and Field Hospital Section respectively.

Each motorized company at present consists of 5 medical officers, Captains or First Lieutenants, and 122 men; twelve heavy motor ambulances, one motor car for the officers; three motorcycles with sidecars, three motor trucks for the equipment, a water cart and kitchen each on truck trailer. Each ambulance holds 8 sitting or 4 recumbent patients, a driver, and ambulance orderly. It is contemplated that the number of ambulances shall be increased and that certain companies

FIG. 16.—SUBTERRANEAN AMBULANCE DRESSING STATION.
Les Eparges, Meuse (France).

will be equipped with heavy and others with light ambulances in each division.

The company in action resolves itself into three fairly well-defined sections—a transportation, a dressing, and a litter-bearer section.

In *trench warfare*, owing to the fixed position of long-range enemy artillery, the tendency was to establish one or two dressing stations in positions on good roads to the rear at the points farthest forward to which ambulances could go by day, and usually so placed as to drain several Battalion Aid Posts apiece, thus covering both flanks. These dressing stations were usually from 1500 to 3000 meters from the line (Fig. 16). As a rule, such a station was usually the real ambulance head, but the ambulance head was not necessarily at the dressing station. At times,

for military reasons, the latter had to be nearer, but the advantage of having the two in one is self-evident. At this dressing station were usually one or two medical officers and from 12 to 25 enlisted men. An ideal distribution is: One company on active duty, with headquarters and reserve ambulances at a regulating station on a road common to all dressing station ambulances en route to the rear; one in "alert," in readiness for sudden call, at the train headquarters (or Ambulance Section headquarters, if separate therefrom), one resting and repairing or cleaning ambulances, and one in reserve. A regular roster kept among these three motorized companies gives each a few days in service at the front, a few in "alert," and a few in reserve at rest. The Director of Ambulance Companies is in full charge of evacuation from battalion aid stations to hospitals and is constantly on duty, with headquarters near the support ambulance company. The American Army usually placed an ambulance, even with some risk, at or near each Battalion Aid Station possible to reach by road, and hidden from enemy view; two or three more were held at the dressing station. When a man or several men were wounded they were placed in the ambulance and driven, without waiting for a full load, through the regulating station, without removal from the ambulance, direct to the hospital to which they should go.

These are the basic principles of an ideal distribution, but peculiarities of terrain brought modifications. If the sector were deep and exposure for ambulances great, an advance dressing station was thrown out, and ambulance relay stations provided on the way back. As fast as an ambulance came down loaded from the dressing station, the relay ambulance was sent up to take its place, and the vacancy caused in the relay station was later filled by an ambulance from the regulating station. Such a regulating station *in activity* could be converted into a so-called "ambulance company triage." *Triage* means sorting —a place for the classification of casualties and their distribution to the special hospitals to which they pertain. The triage in trench warfare, however, was not usually necessary.

Battalion Aid Posts, where an ambulance was left, constituted what were known as ambulance posts or, as the men called them, "cab stands."

The Dressing Station.—The principal function of a dressing station is to receive, classify, and forward patients promptly to their proper destination; to give them hot food and drink; to readjust loosened dressings or splints; and, in emergency, to complete the unfinished work of an overburdened Battalion Aid Station by administering antitetanic serum, completing diagnosis tags, etc.

The dressing station must always be prepared to treat and prevent shock, for it is there that shock begins to be noticed and preventive measures are most needed.

A dressing station should have an operating and dressing room, as well as the usual dependencies, a reception room, a refreshment room, an emergency room, etc. Sucking wounds of the chest should be

temporarily closed by a whip stitch through the skin, or well plugged, and, above all, the cases in profound shock held for a favorable reaction. In the allied armies it was considered a serious matter to have to explain the death of a patient en route.

The chief end subserved by a dressing station *in trench warfare* is to provide a place in close proximity to battalion aid stations where wounded men can be collected, sorted, and distributed; where they can be fed and given hot liquids, and can be patched up for the journey before them. Incidentally it is a place where dressings can be done and, on rare occasions, grave surgical emergencies met.

Each Battalion Aid Station should have near it such number of Ambulance Company litter-bearers as the activity of the sector requires for littering men back to the dressing station.

Ambulances must bring back to the front a quantity of blankets, litters, Thomas splints, etc., equal to the total evacuated with all the wounded men; otherwise the small Battalion Aid Posts would soon run out of supplies. The French would not allow a man to be removed from his litter until finally disposed of in the hospital to which he was destined to go.

When a raid is planned arrangements must be made to concentrate reserve ambulances at the regulating station.

In a War of Movement.—Here the handling of ambulances varies greatly from the foregoing. Routes of evacuation are all important. Most great battles have to be fought over villainous roads, jammed with vehicles and men. The first great problem is to get the ambulances into action. Perhaps the best tactics on a narrow front with a difficult road problem is to pool all ambulance companies and send out with the attacking force—which frequently consists of two regiments in column of battalions—the necessary detail of ambulances of two companies, holding the rest in "alert" under the Director of Ambulance Companies in one place—the ambulance park. As the battle develops the other companies can be despatched as needed.

When, from previous reconnaissance, the ground over which a fight is to take place has been found too difficult for motors, the first short hauls may best be made by the new medical combat wagons on the battlefield with their battalions. These should be forwarded to join their battalions if they have been left in the rear. They can generally get around a block and be on hand at the front to carry wounded to available collecting points for motor companies in the rear. If a bad block occurs, as is apt to, these wagons may be the only wheeled transportation the Medical Department has on the battlefield, as they can usually cut out of a road or go over a field and around a jam.

Eventually, when the Director has fed all of his ambulance companies into the battlefield, they here function as companies and not as a "jitney" service, as the trench warfare system has been called. The Company Commander gets as far forward as possible, establishes his headquarters in the field, throws forward his dressing station or stations, and keeps in touch with the advancing regiments by means of

the liaison officer of his company in command of a litter-bearer section. This officer's business is to keep in touch with the regimental medical officer and, directly or through his company commander, with the Director of Ambulance Companies. With each Battalion Surgeon is a man or two of his section whose entire duty it is to keep him informed of change in location of the Battalion Aid Station. *Liaison between the Ambulance Company and the regiments is absolutely imperative.* It is one of the *chief duties* of a Director of Ambulance Companies and is therefore his responsibility. Hence, his post is in the triage or, better, between it and his collecting points. The tragedies from liaison lost can with difficulty be talked away. Ambulances are despatched to battalion aid posts or, as usually happens, to a collecting point for wounded

FIG. 17.—TRANSFER OF RECUMBENT WOUNDED TO AMBULANCE DURING BATTLE NEAR NANTILLOIS, OCTOBER 12, 1918.
This was the nearest to the line that the ambulance could go.

(Fig. 17). The company commander should have some ambulances in reserve for large groups of wounded suddenly calling for help. He should not let out all at once, and should not strew them all over the sector in anticipation of possible losses. The ambulances will be hit now and then, but they will do a power of life saving, if well handled, before the unlucky shot which puts them out of commission. In fact, ambulances in the Argonne-Meuse were riddled with bullets, spattered by shell fragments, and even wrecked by some, and repaired in the field; but they kept on through it all. Men drive day and night for three, four, five days, or more, sleeping by fits and starts, the orderly and chauffeur taking turns at the wheel. *The divisional ambulances must not leave the division field.* They should carry only to the triage and

field hospitals. From here back to the Evacuation Hospital it is the duty of the Evacuation Ambulance Companies. Reinforcement to divisional units should come in the shape of ambulance sections of twenty light ambulances furnished by the Army through the Corps Surgeon. These work well forward, and, being rapid and of little weight, are of invaluable service.

At times, due to road blocks and routes impossible for trucks, the connection with the rear is temporarily severed, and news comes into the triage that wounded are accumulating at the front and cannot be evacuated. In such a case there are two alternatives:

FIG. 18.—SLIGHTLY WOUNDED, 32D DIVISION, TRANSPORTED BY AMMUNITION TRUCK NEAR MALANCOURT, MEUSE (FRANCE), SEPTEMBER 28, 1918.

1. Forward the essentials of a Field Hospital past the block and care for the wounded as well as possible until the roads open; or, in case of absolute failure to get even this hospital forward,

2. Send up dressings, litters, and urgently needed supplies by pack mules or horses, wheeled litters, etc., and care for the wounded at collecting points as best one can.

Here is the value of having extra animal-drawn vehicles with the corps, and small pack trains as well as ambulance sections held in readiness *well forward* where reconnaissance has furnished information that such a distressing emergency is possible or probable. These are special or additional medical units not normally needed in the division, but imperatively demanded when the call comes. This is a prime function of corps medical troops. But if a battalion medical cart, as described under the battalion combat equipment, is found to be feasible, there

will probably be no need for animal-drawn organizations in a division or corps in most countries with roads.

The situations calling for widely varying tactics would require a volume alone to discuss. The above is cited merely as an illustration of how ambulances may function in trench and open warfare. Many times Division Surgeons used their ambulance sections in a totally different manner with entire success, thus practising the art of war.

Bearing in mind all that has been said of the qualities to be possessed by battalion medical officers as to courage, physical development, and ability to move quickly, we must add to these, in the case of medical officers and men with ambulance companies, great ingenuity in difficult

FIG. 19.—GROUP OF WOUNDED COLLECTED AT THE MOST ADVANCED DRESSING STATION OF THE 35TH DIVISION, CHEPPY, MEUSE (ARGONNE FOREST), SEPTEMBER 29, 1918.

situations, a thorough knowledge of military movements and maps, and all of the alertness and presence of mind of an emergency hospital surgeon. The comparison is a just one. No other than a medical officer can be responsible for holding on to the spark of life that wavers in that most dangerous and dreaded epoch in the operative period of the seriously wounded man—his passage through the pandemonium of a battlefield to the hospital. None but trained medical troops in absolute control of the medical officers can bring the percentage of salvage from these wrecks to the high point from which our medical profession can point as the contribution of medical science to the winning of the late war.

From all that has been said it can be readily and clearly understood

that no matter how skilful and humane our representatives on the battlefield may be, they are utterly helpless when their transportation fails them. Tardy delivery of wounded men means to the surgeon today more than ever it did—surgical failure and an increase in war cripples from infection.

Slight wounds, when treated in time, are quickly remedied, freeing a bed in the rear for another patient, and reinforcing the line. When treatment is delayed they become formidable cases and too often end in gas gangrene and amputation, or slow and painful suppurative conditions, with osteomyelitis, at the rear. In the end, an efficient medical service will become one of the chief, and, when the whole nation has put forth its last effort, *the* chief source of reinforcements.

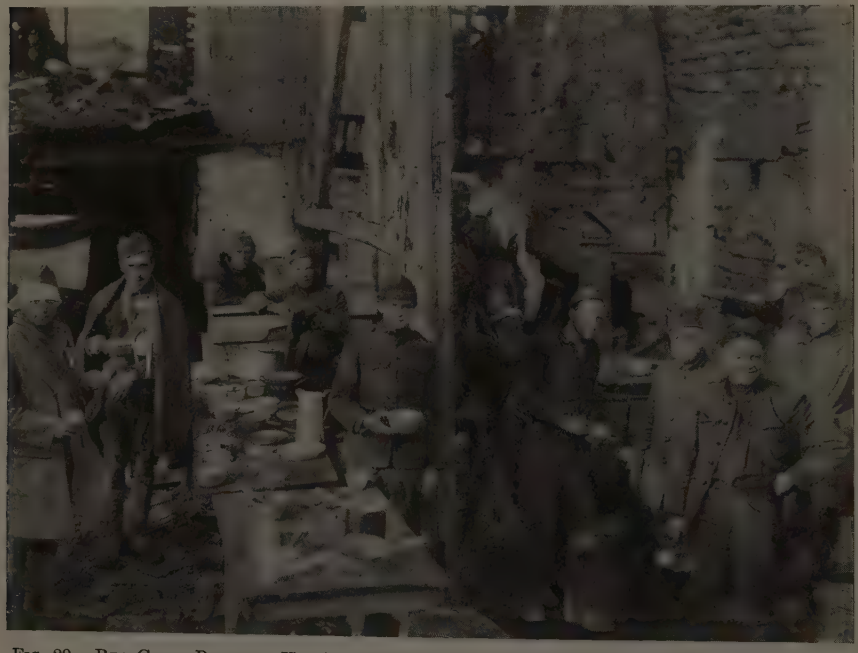


FIG. 20.—RED CROSS POST FOR HOT DRINKS NEAR DRESSING STATION CHEPPY, MEUSE (ARGONNE FOREST), OCTOBER 10, 1918.

The Functioning of the Dressing Station in Open Warfare.—There are advantages in considering the dressing station as a substitute for the old regimental aid station. To it, by hand and wheeled litters, are brought the wounded by bearers of the Ambulance Company; and from it, by ambulance, truck, or any other vehicle, they are evacuated as rapidly and as soon as possible. Ambulances are usually in touch with the dressing stations. Strenuous efforts should be made to give hot liquids to wounded who can swallow, and to blanket the patients well. The degree of professional work depends on the shelter, the facilities, and the inflow. Dressings, splinting, and tagging can usually be done if the influx is not too great. Hot liquids can frequently be provided,

but little can be done for the gassed save transport them to the rear. Walking wounded are directed to the triage (Figs. 18–20).

The Field Hospital Service

Trench Warfare.—In trench warfare Field Hospitals can be more dispersed and specialized. No triage is needed, and short stays can be prolonged. Before entering into detail, too much emphasis cannot be laid on the cardinal principle that a Field Hospital is an emergency hospital for the field of battle and must be prepared at all times to move with the division into a war of movement. Hence its combat equipment should be ready at all times, and it must be prepared to shed its self-made comforts and to leave its more elaborate paraphernalia for rear organizations to take over. The Field Hospitals should be situated on good roads to the rear, readily accessible from the regulating station or dressing stations of the ambulance service behind which they function. All wounded and sick concerning whom a doubt exists as to whether they can stand the longer trip to the Evacuation Hospital or are liable to be fit for duty again in a few days, are sent there direct. Usually there is a surgical hospital for non-transportable patients as near as possible to the regulating or dressing stations.

Not much to the rear was the Gas Hospital. One more was reserved for the sick, and the last was used by some as a rest station for exhausted soldiers and for those with minor ailments; or this function was included in the work of the gas hospital, and the tentage and men of the fourth were divided, one section to run a hospital for skin diseases, and the other a venereal disease labor camp. In general terms, with one surgical, one medical, one gas hospital, a fourth is left to meet the special local necessities. An epidemic would claim it for contagious diseases; great activity, for slightly wounded, etc.

The hospital for non-transportables should have one or two operating teams assigned by the army to the division for those cases whose condition is such as to render them temporarily non-transportable, such as patients in deep shock, sucking chest wounds, extreme head and belly wounds, gunshot fracture of the limbs with extensive laceration, and severe hemorrhage, as no patient should leave a Field Hospital with a tourniquet on. Shock is the main consideration. Operations should be limited to very extreme cases where further delay would almost certainly cause death. They should not include over 1 per cent. of the total wounded, for a Field Hospital is not the place for an operation: first, because the equipment and surroundings are not ordinarily such as to give the wounded man a proper chance; second, because once operated upon, the man is immobilized for days and the hospital is not kept clear for emergency work; third, because no matter how desperate the case may seem, the disadvantage of a trip of a few miles further back over a good road is of little consequence, as against the infinitely greater advantage of having the man under conditions offering a chance for modern aseptic surgery out of shell range, and a bed where he can usually remain until convalescence.

The hospital for non-transportables usually functions in a building in some town; otherwise in tents, or, when cover is badly needed, in certain privileged circumstances, in a quarry, or a cellar of a brewery, or other large building in ruins. The equipment, mode of functioning, etc., in trench warfare give this hospital a tendency to assume the appearance and character of an evacuation hospital in miniature, with the important difference that within a few hours it can be on its way with the division, in trucks, leaving behind its surplus comforts. Our analysis of the Evacuation Hospital should suggest what is here left out.

Equipment of Field Hospitals.—There should be eighteen ward tents, 16 x 50 feet each, preferably set in a frame and double-walled, without tent poles and guy-ropes, with a generous air space between to protect against extremes of temperature. Windows should be provided for ventilation and direct light, and side entrances by which, through covered ways already attached to the tents, patients can be transferred from one to the other without being exposed to the elements. There should be cots for 250 patients. Those ward tents not intended for patients are for receiving and sorting, operating, cooking and mess tents, and housing of the personnel.

Heat is to be supplied by two stoves about 30 inches high. The whole equipment needed for a Field Hospital can be loaded on twelve trucks. The equipment is sufficiently liberal to meet all real emergencies and to provide as much comfort as possible in the field. There is an abundance of medicines, dressings, blankets, splints, and operating instruments and material. The model Field Hospital equipment should include a bathing unit, a laundry unit, an electric light unit for the operating room, a small autoclave, a transfusion apparatus, an oxygen-nitrous-oxid anesthesia unit, a shock heater apparatus, two operating tables, and a rolling kitchen and mess equipment. The small articles should all pack in stout, small boxes of uniform size, well labeled, and classified as to their employment.

In a **war of movement** field hospitals are not ordinarily to be ordered to take position in the field in anticipation of the military situation until the battle necessity develops. They are held together in the rear until it becomes clear where they are most needed and may best be utilized. The field order for the battle need fix only two positions for these Sanitary Train units:

1. **The Ambulance Park.**

2. **The Triage Hospital.**—The most advanced Field Hospital is the triage or sorting hospital. It should be as far front as possible, generally 5 kilometers from the line, and on a road covering all parts of the line. When a triage was left 8 kilometers or more to the rear of that line, the reserve triage "leap-frogged" it, if possible, as will be described. Near it should be the gas hospital. To this point flow the wounded. Here records are made for the division, giving the name, rank, organization, date, type of wound, and disposition of the case, and the field medical card bearing the same information is attached to the soldier's uniform. Here also dressings and splints are readjusted, great surgical emergencies

met, and the patients, now classified, are fed, warmed, and sent either to the Gas, Sick, or Evacuation Hospital. In case a mobile hospital does not arrive in time, it is here that the operating team handles non-transportables, as heretofore described. This is the regulating center of the medical service in battle, and here are generally to be found the Division Surgeon, the Medical Supply Officer, the Consultant in Orthopedics, the Division Medical Gas Officer, the Divisional Psychiatrist, and, from time to time, the Director of Ambulance Companies and Field Hospitals, and the Commanding Officer of the Sanitary Train. This is the point at which all these officers can be of most service, because here near the battle line they get in direct touch with the disabled fresh from the field, can quickly anticipate the need for reinforcements, can

FIG. 21.—TRIAGE (SORTING STATION) IN OLD CHURCH, NEUVILLY, MEUSE (FRANCE), SEPTEMBER 20, 1918.

best handle tactical questions of the Medical Department, and can prevent loss of men to the division by unnecessary evacuation to the rear.

This triage is the main source of first reliable information to the Division Commander of his losses. It is well for the Division Surgeon to have his personal assistant, a Major, stationed at the advanced Divisional Post of Command, well to the front, to keep him constantly informed of the changing position of troops. By constant communication with G-1 this officer can notify the Division Surgeon of the return of empty ammunition trucks which can be utilized to collect and carry back wounded collected at the triage or collecting points even further to the front, as the ambulance service is never anywhere nearly sufficient in a sharp battle.

The other two hospitals may work advantageously further to the rear. One is a reserve hospital, and the other is in readiness to "leap-frog" the triage in front of it when the advance leaves it too far in the rear. This second triage hospital now moves rapidly forward, and, passing over the one in operation, establishes a new triage beyond in the same relative position to the division. In like manner, the reserve hospital can establish in front of the gas hospital, picking up in passing its degassing equipment. All this means that a constant stream to the rear must be kept going—the mission of the evacuation ambulance companies, supplied by the Chief Surgeon of the Corps or Army. Once full and without means of sending patients to the rear, a Field Hospital is condemned to immobilization unless it can find a building nearby in which to leave its patients, with certain of its personnel to care for them.

This is only one method of employing field hospitals. There are many others, selected on account of the terrain, condition of roads, and military eventualities.

It may be a matter of surprise that no mention has been made of seeking cover for field hospitals. Beyond keeping some 5 to 10 kilometers in the rear of the front line, it does little good to seek cover. Many of our hospitals came to the point where they worked in plain view of the enemy, with a large cross, 30 feet from tip to tip, well displayed. The important thing to observe is that no firing batteries are near by and that cross-roads are avoided. To get away from firing batteries is really a difficult problem, however. The amount of artillery used in a modern battle is enormous, and usually these undesirable neighbors are all too friendly. Camouflage is, frankly, a mistake. It merely awakens the suspicion of the enemy and is pretty nearly sure to be discovered, and so become the object of vicious shelling.

It is impossible to elude the self-evident conclusion, when treating of these active units, that the Medical Department in war should be represented on all staff councils as a branch of G-3, which deals with military operations, and not as a branch of G-1, which represents supply. The application of the Medical Department on the field of battle is so inextricably bound up with the movement of troops and tactical considerations as to require its ever-present representative in these councils.

The *Medical Supply Officer* has two trucks and a little squad of men. He is in constant communication with the Division Surgeon, under whose personal direction he works. This officer should know not only where every unit is but also the needs of each one. His supplies are obtained direct from the nearest Army Medical Dump in the rear, in anticipation of these needs.

The Division Mobile Laboratory is under the Sanitary Inspector, and upon it largely rests the scientific basis for the practice of epidemiology in the division. It is rarely called upon for report in connection with wound bacteriology, but in clinical laboratory diagnoses, in separating out "carriers," and in rapid water analyses it has become in practice a necessity in a division.

The Division Surgeon.—The last element, the Division Surgeon, is left for us to consider. This officer, a Lieutenant Colonel, represents the Medical Department in the Division. He has a double function:

1. He is a staff officer of the General commanding, his technical adviser and his representative in the supervision of all medical, dental, and veterinary officers of the regimental and battalion service.

2. He commands all Divisional units of the Medical Department, such as Field Hospitals, Ambulance Companies, and all medical officers attached to the division. On his personal staff are:

(1) A Division Sanitary Inspector, under whom should be
  (*a*) The Mobile Laboratory.
  (*b*) The Division Water Specialist, and, when in camp,
  (*c*) The Sanitary Squads.

(2) The Medical Supply Officer.

(3) The Division Consultants: An orthopedist, a psychiatrist, a urologist.

The Division Surgeon is under the command of the Division Commander. From the General commanding comes the authority to carry his plans into effect. From his brother officers of other arms of the service will have to come the co-operation necessary to make his mission and their own successful. He is himself under the technical supervision of the Corps and Army Chief Surgeons. He has to be thoroughly informed of the tactical situation and should know as much of the intentions of his commander as it is possible for the latter to inform him, for, as there is no fight in which the Medical Department does not have to play a part, it is imperative that he be furnished all the information needful for him to play his part creditably. He is responsible for the care of the sick and wounded, and to assume intelligently a great professional responsibility—the chief reason for his elevated position—he must be thoroughly alive not only to the prevention of disease, but to the current trend of surgery and medicine in peace and war. He must thoroughly train his men and officers and supply all medical units at all times. The rehearsal of his duties and responsibilities would be well-nigh endless, but, briefly, he is there to apply the medical sciences to war in a co-ordinate manner with other arms and to the best interests of the service. This tells it all, and we will leave to the good sense of the reader to see the necessity for a trained man of unusual ability for what has been said to be, as far as personal satisfaction is concerned (after that of the Battalion Medical Officer), the greatest privilege in war for a man of our cloth. The first is the doctor on hand where his services are most personal and most appreciated; the second puts into action, and is the first of a long and honored line running rearward, to direct the forces of a great profession in saving men to fight again, preventing losses from disease, and at the end turning back to civil pursuits the minimum of maimed and otherwise incapacitated.

There is an increasingly strong feeling among certain officers who have been in France that it would be better to substitute for these four ambulance companies two units organized for the service that each is

to perform; one a litter bearer battalion, the other an ambulance section comprising all of the ambulances in the division. There are many reasons to believe that the practical application in the Great War of the medical sciences would warrant organization not unlike that of the engineers, with their engineer regiment and engineer train.

The Mobile Hospital
(Advanced Mobile Surgical Hospital)

This should be a Corps unit, as it meets special situations for the divisions and would be about one-third of an Evacuation Hospital in bulk of equipment, personnel, and bed capacity. In capacity for surgical work and administrative significance, the Mobile Hospital is the nucleus of an Evacuation Hospital and its representative on the field of battle for cases impossible for the time being to evacuate further to the rear than the Field Hospitals—the so-called non-transportables of a large engagement. In anticipation of a large battle, or in event of an emergency which Field Hospitals are not prepared to meet, the Corps Surgeon has this unit dispatched as far front as possible, preferably to the triage. To accomplish this rapid movement—which should be consummated in hours, not days, as the first models required—the elaborate equipment of its congener, the operating center of an Evacuation Hospital must be cut down, and the delicate apparatus requisite for all definitive surgery must be sent up compact, assembled, and prepared to function. Later, when the troops gain their objective and quiet down again, around this nucleus can be assembled in many instances a new Evacuation Hospital, either by moving up the Evacuation Hospital in the rear, or by supplying additional bed space and elements lacking for more permanent work.

The total weight of the equipment is about 80,000 pounds, with a cubic capacity of 5500 feet. To transport this equipment requires twelve 3-ton trucks with eight trailers of $1\frac{1}{2}$ tons each, or sixteen 3-ton trucks without trailers; or, by train, four Continental or two U. S. box cars, or two U. S. flat cars.

The personnel is: 18 medical officers, 20 female nurses, and 90 enlisted men.

The general mode of functioning will be that of the operating center of an Evacuation Hospital, insofar as the exigencies of the military situation and the rate of flow of wounded will permit.

Counting one hour as the least possible time required to do a serious major operation, two tables will yield about 48 cases a day and will require six operating teams.

Evacuation Hospital

This is the regulating center of the medical services for the professional care of men who have survived casualties at the front, and is, as it were, the triage for the Medical Department from which are distributed to hospitals in the rear all cases which cannot be cared for here to the completion of their convalescence. In addition, the Evacuation

Hospital makes provision for temporary and definite treatment of certain selected cases not advisable to send to the rear. In times of great activity these cases are brought down to the irreducible minimum, where further evacuation would greatly endanger their lives. In time of relative calm or small engagements it handles practically all cases itself which can be disposed of in about two weeks. This hospital is the pivot upon which the man's life, limb, and future usefulness turn. Here is accomplished the bulk of the urgent surgery of war, the surgery which cannot be postponed—the vital part.

The Evacuation Hospital should be located on the railway, near a water-supply, as near to the front as is practicable—generally from 15 to 25 kilometers. It should be on a good road to the rear, easily reached by tributary roads draining all parts of the front served. It should not be in direct and intimate association with the railway depot, ammunition dump, military depots and troop cantonments, but all by itself in the open country, preferably a half-mile away on a spur of the railroad. This latter requisite is the most difficult of accomplishment in war, but upon the isolation of this unit depends its only real chance for safety against avions, its most formidable enemy. It should be plainly marked by a black cross of tarred stones in a whitewashed disk, not less than 30 feet from tip to tip.

The elements of an Evacuation Hospital should embrace:

The triage.

The operating center for the more seriously wounded.

Hospitalization quarter for non-evacuables.

Quarter for the evacuable, with an operating center for the slightly wounded.

Quarter for the reception and treatment of the gassed.

Quarters for the personnel and the dependencies, such as amusement tents, Red Cross tents, kitchen, etc.

In Trench Warfare.—In the late war the English and French, realizing that the professional center of the medical service had moved up from the base to the front, and being settled for three years in a condition more or less resembling a siege, boldly placed large and elaborate hospitals at railheads 15 to 20 kilometers from the front line. These hospitals were generally equipped for all specialties, the larger ones accommodating from 2500 to 3500 patients, and were usually immobilized in permanent barracks: the French, in the wooden Adrian or Service de Santé barracks, or the Bessonneau tent; the English, in huts of a like type, or the Nissen corrugated iron, arched hut, or in Marquée tents. Being permanently established behind a practically unchanging line, and in view of the extremely trying nature of the soldier's front line service in which he was constantly crouching in trenches and shaken by artillery fire; being obliged to conduct offensive objectives and to repel enemy attacks at night, frequently by hand-to-hand fighting, these hospitals made unprecedented arrangements for beautifying their sites and their wards and for providing for the soldier all the comforts, amusements, and conveniences possible.

The day came, however, as it had to come, when the price was paid. These hospitals with all their elaborateness and huge cost may have rendered a sum total of service far in excess of their cost—they probably did. But the facts are, nevertheless, that by two mighty thrusts Germany in her death agony swept over these magnificent hospital cantonments, and in a trice the medical services of Great Britain and France had lost a large part of the machinery they had been depending upon to cushion the blow of a great wave of disabled thrown in upon her base and evacuation system.

The American Medical Department was educated in these centers on its arrival, but it is only justice to say that the teachings of Straub and Munson and the Fort Leavenworth School were too deeply rooted to be seriously shaken, and our Evacuation Hospitals were kept reasonably small and very mobile.

But in equipment and systematic administration for a kind of warfare heretofore untried the demonstrations and frankly expressed experience of French and British gave us for the adaptation of our Evacuation Hospitals as well as of our entire medical service a foreknowledge which had cost them, and would have cost us, many lives, much suffering, and our bitter regret.

The administration of the Evacuation Hospital, as well as that of other medical units, is influenced by the scientific fact that a shell wound is practically always infected, and that the major part of these infections is due to banal micro-organisms chiefly carried in on the clothing with the projectile and requiring for successful colonization dead or devitalized tissue. This means that such cases should all be operated upon within twelve hours from the time of the production of the wound —the usual period of microbic inoculation—in order to get the best results from an economic, military, and humane point of view. Such cases, properly operated upon, can usually be returned to the lines, if the anatomic damage is not too great or does not seriously affect the specialized movement of a soldier, in from three to five weeks. Hence, time is one of the chief elements to be considered in the removal of the wounded to their definite point of operation, where the wound should be opened, the projectile and germ-laden clothing removed along with the débris and devitalized tissue—*i. e.*, débridement and epluchage—the part placed at rest, and the wound left open with a flat dressing until bacteriologic examination shall warrant its closure. This suture is usually possible in from three to five days, with subsequent aseptic healing. The notable exception to this practice is seen in joint wounds.

Thus, the Evacuation Hospitals and hospitals continuing their professional work in the rear should be looked upon as vast repair shops for men, and as of prime importance to the troops as an arm of offensive warfare in supplying reinforcements from among men lost to the colors for long periods, or permanently, in all previous wars.

Sorting at the Evacuation Hospital.—In reality, sorting is done everywhere that men are sent, because a medical unit that does not classify its cases has no system and cannot work at its highest point of

efficiency. Here at the Evacuation Hospital triage is imperatively required from the fact that men have to flow through their proper channels to avoid hard knocks, and the stream has to be given the width of channel necessary, and the corresponding force to handle it, or it will dam up, stop the current, and overflow. Every second of time counts, and there must be a one-way current everywhere, and no retracing of steps.

At the entrance to the unit is a well-heated receiving ward, barrack or tent, with its receiving or admission team. These men collect the wounded or sick man's valuables into a paper bag inscribed with his name and hospital number, and forward them to the Evacuation Unit for storage under lock and key against the time when the man may be discharged or evacuated. His diagnosis tag is taken up, and the information on his field medical card is transcribed on the usual forms. This can be done at the rate of one case every three minutes, or 480 a day. *Without these records the War Risk Insurance, the military commander, and the man's family would be deprived of vital information.*

The litter squad now carries the man further on, and a team of 3 men undresses him and throws his soiled clothing through a hopper outside the tent. If the man is a "sitter" and not severely wounded, he is directed, instead, from the administration desk to the dressing room, and after surgical attention there, and some hot food or drink, is sent to the evacuation quarter for immediate evacuation. If the man is sick he is sent from the triage to the medical quarter. The gassed are usually not removed from the ambulance, but are sent direct to the gas quarter.

The triage officer should be an experienced surgeon himself. He must be a quick diagnostician. During the bath of the wounded man this officer examines the wounds and makes a provisional diagnosis, calculating the relative gravity of the case and deciding whether the man can wait his turn for operation or must be given precedence over others. He makes careful search for nerve and blood-vessel injuries, and records his provisional diagnosis on the field card, as well as all morphin administered.

If the man is in shock, he is immediately transferred to the adjoining shock room, where the temperature is kept uniformly at 90° F. and hooded shock tables are prepared. This room is served by a shock team with facilities for the transfusion of gum solution or blood, and instruments of scientific precision to check on the patient's condition and response to treatment.

In the room for bathing and diagnosis Colonel Joseph M. Flint used to great advantage an enlisted man to sketch the location and character of wounds, dictating the legendary sign used to designate the type of wound and placing the completed sketch in the field card envelope.

From this room, if necessary, the patient is carried through a covered passage to the radiologic department, which contains a waiting room for those ready for operation, and who carry the notes of the radiologist and the indelible marks on the skin to guide the operator.

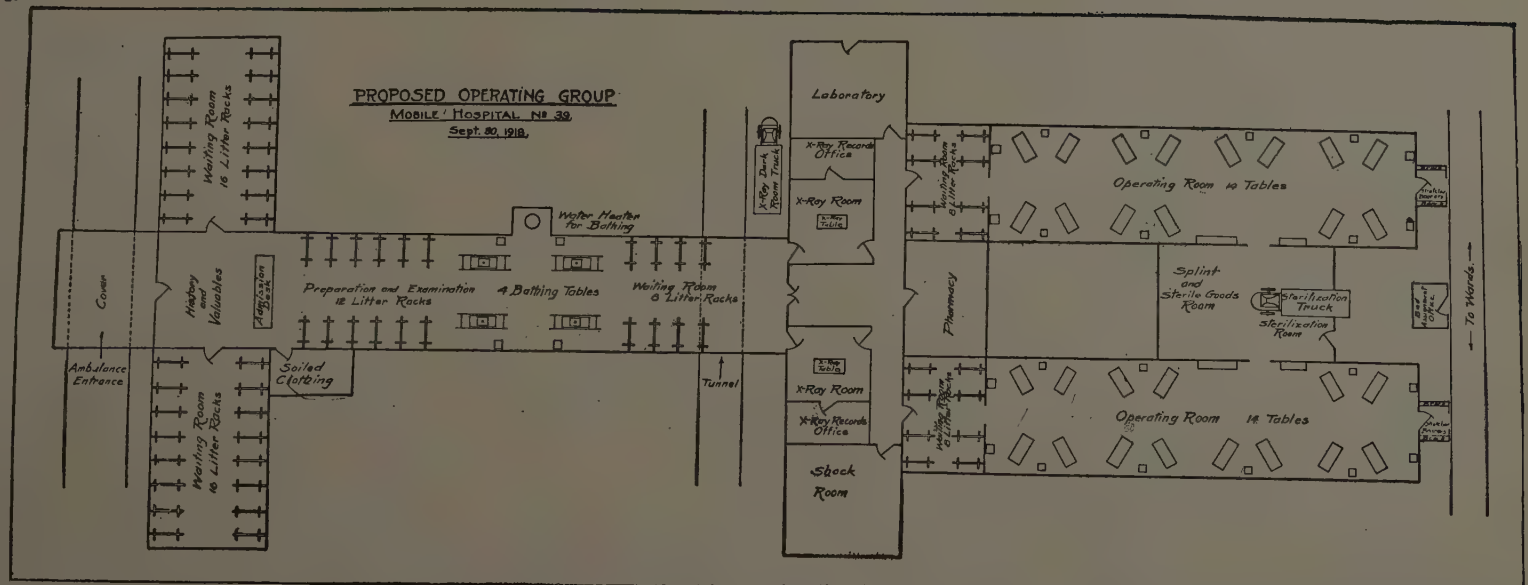


FIG. 22.—PLAN OF A MODEL OPERATING GROUP FOR EVACUATION HOSPITAL FURNISHED BY LIEUT.-COL. JOSEPH M. FLINT, M. C., COMMANDING MOBILE HOSPITAL NO. 39 (YALE UNIT IN FRANCE).

On a signal from the operating room the patient is admitted. This operating room normally contains six tables. The surgeon now inspects the data contained in the field card. Notes of the operation are dictated by the surgeon to the anesthetist, who places them on the man's field medical card. Movable electric lights and slings for arms and legs should be rigged up on wires over the operating tables. An operating head-light is almost indispensable.

Each team receives a débridement set and a standard set of dressings for each case. The *débridement set* is packed in a tin box and contains:

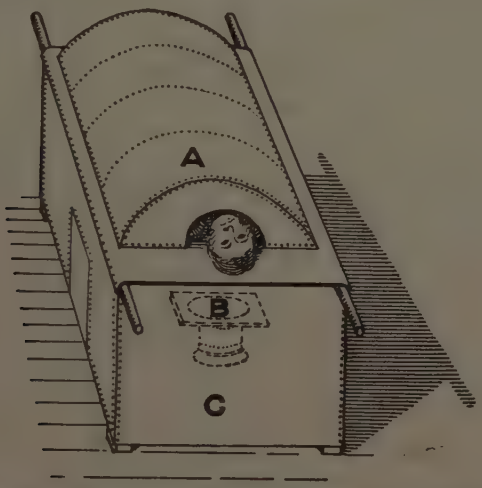


FIG. 23.—A, MOVABLE HOOD CLOSED AT ONE END; B, PRIMUS OIL STOVE WITH METAL PLATE; C, INCLOSED LITTER SUPPORT WITH SIDE OPENING TO INTRODUCE LIGHTED STOVE, THE LITTER FORMING THE TOP.

Hood and litter support to be portable framework on which may be tacked blankets or cardboard.

Tait's straight clamps, 4; Tait's curved clamps, 8; Kocher's clamps, 4; Terrier clamps, 6; mouse-tooth forceps, 2; scissors, curved, 1; scissors, Mayo, 1; Allis' forceps, 3; towel clips, 4; needle-carrier, 1; retractors, small, 2; grooved director, 1; scalpel, 1; needles (two of a size), 6.

The *standard dressings* (Flint) were:

Article.	Number.	Size, inches.	Quantity, yards.	Material.
Wipes or sponges.	30	4 x 4	6	Gauze
Wipes or sponges.	25	2 x 2½	3	Gauze
Dressings.....	6	4 x 8	3	Gauze
Bandages.....	2	3 x 4	3	Gauze
Sheets.....	3 pieces	2½ x 2½ feet		Muslin

By filling the pad with absorbent cotton great economy of gauze is secured.

In case special instrument sets may be required—abdominal, amputation, bone, craniotomy, lung—these are assembled and held in their respective boxes, ready for instant call.

Two pairs of rubber gloves are handed to each team when it goes on

duty. When the operation is completed a shipping tag is affixed to the patient, bearing the words "evacuable," "non-evacuable," the disposition not desired being crossed out.

Splint teams should, if possible, always apply the splints. The litter squad on duty in a waiting room, just outside the operating room and at its further end, is now called. The patient is removed by these men, and the sergeant in charge of bed assignment, in a little office adjoining, gives him his bed number. This office is the regulating center of the whole hospital machine, and knows what beds are available at any given moment.

In evacuation all patients are required to pass out through the evacuation office. When a patient is fit for evacuation he is transferred to an evacuation ward. Dressings and the condition of patients are verified before this evacuation. The evacuation sergeant delivers to the patient his bag of valuables and recovers from the field medical card envelope all records except the card itself, which bears the final diagnosis. The operation notes are copied from the card for the completion of the hospital records. These records are delivered to the registrar.

There is at the hospital an *Evacuation Officer* who is also a liaison officer and represents the Chief Evacuation Officer of the Army. In addition to keeping an oversight of evacuation wards and the office, he arranges for trains, renders reports which cause them to be sent, controls property exchange in litters, blankets, pajamas, splints, etc., and directs the Evacuation Ambulance Company service.

Surgical Teams.—These consist of one surgeon, one assistant surgeon or surgical nurse, one anesthetist, and two operating-room nurses, one for handling sterile and one non-sterile articles. They work in groups, under ideal conditions each team being on duty in the operating room eight hours in constant activity, eight hours in attention upon its wards, and eight hours in repose. Periods of duty begin at 12 M. In an offensive there are often but two alternating groups. Allowing one hour of operating to each *serious* case, we have for six tables and twelve teams an output of 144 cases a day, of which 50 per cent. will be non-evacuable cases.

In a 500-bed surgical quarter during an offensive, estimating 200 admissions a day, with twelve-hour operation shifts, it was considered that there was need for 2 triage officers, 11 ward surgeons, and, if only serious major cases were operated upon, nineteen operating teams; if moderate and serious cases mixed were to be operated upon, twelve teams would suffice; 61 nurses and 180 enlisted men were calculated as necessary to serve this plant, counting 18 for administration (admissions, evacuations, etc.); 10 for the operating room; 15 for a kitchen for 750 persons; 44 for the wards; 45 for stretcher bearers; 10 for transportation; 10 for the pre-operating room; 8 for undressing and delousing; 8 for the radiologic service; 12 for general work.

Sterilizing Room.—Here there are two teams on twelve-hour shifts. Two men clean instruments, one cleans and repairs gloves and

sharpens instruments. A nurse superintends the storage of supplies, sterilization and standardizing of instrument sets, and in inactive periods details from teams turn to and make dressings for the next offensive. Three enlisted men care for the actual sterilization and the apparatus in function. Instruments are preferably sterilized by hot air, but in an attack they usually have to be boiled.

x-Ray Service.—This requires four teams, two at a time. One radiologist should circulate as needed in the operating room and should be on hand with the fluoroscopic bonnet and movable bedside apparatus to aid the surgeon in finding lost fragments.

Laundry.—Two working teams each, 1 sergeant and 4 men, and handle over 2000 pounds of laundry in twenty-four hours.

For a 500-bed surgical hospital with six tables, two shifts of 28 men each are needed, although eight-hour periods are more economic in the long run.

The foregoing represents Flint's experience in handling a mobile hospital of the early type. It has been minutely described because of its great underlying principles of economic, scientific, and orderly administration which will be of service as a guide in open warfare. Though every comfort and every vestige of elaborate instalment were stripped from it, its general spirit would be found to be of incalculable value in future organizations of this type, as it fairly well expresses the experience of the French in three years of evolution in trench warfare, and the spirit of scientific American surgery.

There are some comments on this exposition, however, which are justified from visits made to many American, British, and French Evacuation Hospitals and from subsequent observations in open warfare. The sudden loss of the hospital areas of both British and French in 1918 by the enemy invasion toward Amiens and Chateau-Thierry caused large numbers of slightly wounded to appear for primary treatment in Paris and other points remote from the lines twenty-four to forty-eight hours and more after the receipt of their wounds. Many of these wounds, however, healed a few days later without infection. Evidently the maximum of twelve hours of permissible delay in operating upon such cases is not nearly so important surgically as heretofore has been imagined.

It is now clear that the Evacuation Hospital should not attempt to operate upon all cases, but only upon selected ones which experience has proved should not be delayed to reach a base. The rest can safely be salvaged further back and an impossible military situation for the evacuation hospital overcome. This is one of the reasons why an American Division can get along with an evacuation hospital of 750 beds for 28,000 men *if evacuation from that point to the rear in a reasonable time is feasible.* In a sharp attack our troops are liable to contribute 800 to 1000 casualties the first day. At an evacuating center in the battle of the Argonne-Meuse it was stated by the medical officer in command of an Evacuation Hospital that during the battle he was counting upon having to hospitalize 10 per cent. of the wounded. This

meant that 20 per cent. would be operated upon, as about 50 per cent. of the serious cases can be considered evacuable.

The Commanding Officer of the 5000-bed Evacuation Hospital at Notre Dame, which was destroyed in the German push toward Chateau-Thierry, stated that 120 seriously wounded required six operating tables and eighteen surgical teams; 180 less seriously wounded, six tables and eighteen teams; and 100 moderately wounded, two tables and six teams.

At this same hospital a quarter for slightly wounded was provided, consisting of a Besonneau hangar and a separate operating group from which patients were stored in evacuation wards as soon as attended to. The hangar held 300 to 400, and the operating groups could handle 450 operations in twenty-four hours. Slightly wounded were here defined as all those in whom there was no wound of a large joint, or fracture of thigh, leg, humerus or skull, or wound "involving any splanchnic organ" (Fig. 24).

Major E. Poole of our Army states that localization of the projectile was needed in 15 per cent. of the slightly wounded, and that three teams would attend to 300 wounded and perform 50 operations a day. It is believed that this estimate can be accepted for our standard.

One of the most ingenious contrivances for surgical emergencies in the preoperating room was what Colonel Safford of the British Army called his "fire-alarm box." This was simply a biscuit tin with one side removed and replaced by paper. This was hung upon the wall and served to furnish at all hours of the day or night sterilized instruments and dressings for immediate use. These biscuit tins contained: Tourniquet, rubber gloves, tracheotomy tubes, hemostats, scalpel, scissors, trocar, hypodermic syringe and needles, surgical needles, silkworm-gut, dressings.

When the contents of this box were needed, the hand was thrust through the paper and they were removed, thus avoiding the confusion of hunting for instruments and dressings separated by distance and confused with a large amount of material for other operations. As soon as used the hole in the paper attracted the attention of the orderly who was in charge, and he immediately replaced the biscuit tin by another one, similarly equipped and sterilized.

It is very desirable to separate prisoners from our troops. The American soldier is unduly excited shortly after his wound, and he thinks and acts like a plucky boy with a bloody nose. The sight of his enemy is apt to throw him into a state of mind at variance with that calm and quiet he needs for conserving the remaining resistance against shock upon which we count to tide him over. A man who has just lost his right arm cannot rest peacefully in a bed alongside the man who represents the force that crippled him for life.

The Equipment of an Evacuation Hospital.—(See Estimate of Equipment, page 119.)

Total weight of hospital, with baggage and rations, 225,871 pounds; without baggage and rations, 195,871 pounds.

Volume in cubic feet, with baggage and equipment, 14,598.70 cubic feet; 13,303.70 without baggage and rations.

A ward tent complete weighs about 1000 pounds; the *x*-ray equipment, 2265 pounds.

Personnel: 65 officers in three tents; 64 nurses in two tents; 297 enlisted men in ten tents.

Patients, 750—30 in tent in the department of evacuation; 25 in the hospitalization department.

To transport these there are needed: 46 3-ton trucks alone, or 32 3-ton trucks with 28 trailers ($1\frac{1}{2}$ tons each). The other four trucks carry rolling kitchens and water-cart trailers. Continental box cars, 15; U. S. A. box cars, 8.

During a great battle the ideal is to group Evacuation Hospitals by twos if railway facilities to the rear, and roads covering the front served, are sufficient in number and are traversible. The location must be on the railway. Save by chance, there is no spur, and it is justifiable to run the risk of bombing and shelling if evacuation facilities are greatly favored thereby. A cross marking the hospital site can be improvised by laying down two canvas latrine screens on the green sward, one at right angles to the other.

Here the essential departments of the hospital are: (1) The triage; (2) the operating center; (3) the hospitalization center for non-evacuables; (4) the evacuation wards.

The dependencies are cut down to the absolutely indispensable: The kitchen; shelter for eating; Red Cross or Army canteen for hot liquids and cigarettes, transportation facilities, with a parking place for motor vehicles; a train shed and loading platform, and a burial place.

It is well to keep within the limits of 1000 beds and order up additional evacuation hospitals when an overwhelming of their capacity is threatened, because when the time comes for moving these hospitals should be ready to extricate themselves rapidly. This is the reason why it is desirable, in anticipation of great battles, all conditions being favorable, to have evacuation hospitals working side by side; for in event of the pushing forward of the railhead, to keep up with the advancing troops, one can evacuate its wounded and take over all the non-evacuables of the other, allowing this one to go forward. In such a case the Mobile Hospital at the Triage must take on increased work for twenty-four or forty-eight hours to cover the transfer. When such "leap-frogging" cannot take place, it is well to have a unit packed and ready for movement in the rear. This has a double advantage, in that in case of a reverse the personnel and necessary material, with transportable patients, can be hurried back to the rear organization, which can be unpacked and installed when the military situation becomes defined.

To meet the emergency created by the ebb and flow of battles everything should be planned for a sudden call to move. Each team should unpack only what is needful and should be drilled to repack hurriedly what is in use, load, and move forward.

In event of a great battle, in a war of movement, the main object to be attained has now become rapid evacuation. Whereas before in active trench sectors the aim has been to operate upon as many as possible to avoid successful colonization of micro-organisms, now a choice between evils is made, and as the flood of wounded and the uncertainty of the result become greater, the gravity of individual cases is justifiably of less importance for the common good and for their own. Slightly, and at times even moderately, wounded in desperate situations are sent to organizations where operation cannot be performed in less than from twenty-four to thirty-six hours after receipt of their wounds. In case of disaster it is better to let the seriously wounded, non-transportables, fall into the hands of the enemy than to kill them by rough evacuation in the confusion and congestion of a retreat. Such terrible situations are avoided by far-sighted and systematic evacuation before they develop. As a preventive of collapse of a medical service the pre-operation train is our sheet anchor. If regular trains are lacking to supply all transportation needs—and under such circumstances they usually will be—improvised trains must be utilized. Medical cases, which are relatively rare, are quite uniformly evacuated.

In the functioning of the Evacuation Hospital all the elaborateness of its stable forerunner in a war of position must be simplified, otherwise the hospital will break down. Equipment and clothing must be dumped and salvaged *en masse* later on. More than ever it is necessary to keep a solid stream of supplies going forward on empty ambulances. Not only must the interchange of articles go on, mentioned as necessary for replacement in each ambulance, but ambulances must be well loaded with all dressings and supplies needed at the front.

Certain records *must* be kept, or all trace of the case will be lost and hopeless confusion will result. These records are required at the admission office of the Triage. Naturally, the clinical records of the hospital will be reduced to barest sketches in time of great activity and movement.

Under conditions of stress in active, open warfare the triage officer must be very alert, and one or more officers must be detailed to assist him. The practice of assigning an operating team here is a good one. It is not enough to detail a medical officer whose information is derived mainly from books. The experienced surgeon is the man needed, and he can be of infinitely more value here than at an operating table. In fact, this is one of the main directing points of a Chief Consultant in Surgery, who should constantly supervise the sorting.

An Evacuation Hospital must be reinforced at such times by operating teams, resuscitation teams, and splint teams. No unit can be constantly equipped for its greatest activity, as in such case these extra teams would be idle most of the time. Such reinforcement is liable to come from the operating centers of base hospitals, and this is one of the greatest reasons why the staff of a base hospital should have experience in front line conditions and their duties in battle.

Again, it is usually impossible to have ideal arrangements for the separate departments. No rigid plan of buildings or tents can be adhered to. It may not even be possible to get the tents up. The terrain varies in each instance, and it cannot usually be selected. An Evacuation Hospital is often called upon to work in a small, inadequate place and must learn to improvise. Many times it will be thrown into a ruined building, supplemented by tents hastily put up where there is surrounding space. It is only necessary, however, to bear in mind the elements of organization and administration laid down as an ideal. This does not pretend to be the *only ideal*, and a diversity of plans too great to include in this work may contain one better suited to particular situations. Whatever plan is selected, it should be simple and should provide for a one-way current. Complicated details condemn an evacuation hospital to immobilization and failure. In the excitement and eternal change of working conditions men cannot have more than a very simple working plan. It would be well at such times to have labor troops assigned to meet great emergencies and to take over routine work which they are capable of performing, thus releasing the Medical Department personnel for duties which are paramount.

At the main group of Evacuation Hospitals where most evacuation is going on—the principal military advanced base—it is well to have the headquarters of the Chief Consultants of the Army, the representative of the General Staff—himself a medical officer of the Army—and the Director of the Army Evacuation Service. This latter officer has a tremendous responsibility. He pools all Army Ambulance units and provides the adequate number to meet the necessities of the moment for transportation of casualties from Field Hospitals to Evacuation Hospitals, thus leaving divisions quite free to meet their local difficulties without detaching their precious transportation to make the long trip back to the railhead. He should even distribute wounded among the various hospitals of a section well connected by good roads, in accord with courier and telegraphic reports of the status of these hospitals. He supervises the evacuation by train, and by frequent attention to units, front and rear, obtains a grasp on the whole situation which in no other manner is so well attained. But the whole structure of the Evacuation Hospital in these intense moments rests on a tripod whose legs are: (1) the admission office and triage, (2) the operating center, and (3) the evacuation system. With these three in co-ordination the mission of this unit will be fulfilled.

The Corps Surgeon

This officer, a Colonel of the Medical Corps, has a triple function under the Corps Commander, that of an advisory nature to the Commander himself on all matters affecting the medical service; that of staff supervision and control exercised over Division Surgeons; and that of command over his reserve and special Medical Department units. These units normally consisted of:

1. A Corps Train which should be composed of a divisional sanitary train plus a pack train and a reserve of animal-drawn vehicles.
2. Mobile hospitals.
3. Three ambulance sections.
4. Such other units, as hospitals for contagious diseases and rest stations, as might be designated by higher authority to meet special conditions.

The Corps Surgeon's staff should consist of one Sanitary Inspector and two Consultants, one in surgery and one in medicine.

He should spend most of his time in personal contact with his Division Surgeons and their problems, and with the Corps Commander or his General Staff. On being informed of approaching combat, he should thoroughly inform himself as to the military problem and our own plans and resources, and request authority to have his reserve elements placed accordingly. There is no time to do this later. Knowledge of the terrain and routes available for ambulance evacuation should largely influence him in selecting the reserve elements to be pushed well forward, available for instant use. This cannot be accomplished properly without consultation between the General Staff of the Corps and the Corps Surgeon, on the one hand, and the Corps Surgeon and the Division Surgeons on the other. In case of far-distant base hospitals, overcongested roads, railway or ambulance, he must be prepared to throw in an auxiliary hospital near the evacuation hospital to care for the slightly wounded. These should be in a town where the 85 per cent. not needing constant attention in hospital can be billeted and visit the dressing room as often as need be.

When not in actual combat, or preparing to enter or retire from that condition, the Corps Surgeon's duties center chiefly in sanitary conditions of rest areas, the bathing and delousing of units in these areas, and the supervision of the sick and injured of Corps troops.

The Chief Surgeon of the Army

The relation of the Chief Surgeon of the Army to the Corps Surgeons and, of course, to the Commanding General, is as expressed for the Corps Surgeons themselves toward their Commander and Division Surgeons.

Under the Chief Surgeon of the Army are the following units:

Evacuation Hospitals.
Special Army Hospitals.
Base Hospitals and Camp Hospitals assigned to the Army. The name Base Hospital should be reserved for those hospitals serving a base. The hospitals should be known as Army and Cantonment Hospitals respectively.
Medical Supply Depots of the Army—one Army Dump, one Corps Dump, for each Corps.
Sanitary Trains, Army.
Ambulance Sections ("S. S. U.").
Evacuation Ambulance Companies.

An Instrument Repair Shop and mobile group.
Convalescent Camps and Depots of the Zone of the Army.
Field Service School, when not in open warfare.
Attending Surgeon's Office at Headquarters.

On his staff are:

(1) A Sanitary Inspector (a Colonel), who should have under his command the Army Mobile Laboratory and the permanent Sanitary personnel and the sanitary squads for the Sanitary Areas into which the Army is divided.
(2) An Evacuation Officer.
(3) A Personnel Officer.
(4) A Supply Officer.
(5) A Chief Dental Officer.
(6) Six Consultants, as follows: One for medicine, one for surgery, one orthopedist, one psychiatrist, one urologist and dermatologist, one *x*-ray technician.

The scope of work of a Chief Surgeon of the Army is indicated by rehearsal of the units under his control and supervision, and to perform these duties well requires a rare man. His chief solicitude should be for the evacuation system rearward from Field Hospitals, the supply system, sanitation and prevention of disease, and the training of all Medical Department personnel in the Army in the best tactical, medical, surgical, and sanitary practice, with a view to the unification of the medical service.

Hospital Trains

Although under the Chief Surgeon of the Expeditionary Forces they will be described here, as the Chief Surgeon of the Army is vitally interested in their loading and distribution.

Heretofore Hospital Trains have been specially constructed for the American Army. Under such stress as the English and French suffered it would probably be necessary to have, as they did, regular and improvised trains. Our regular train usually consisted of two combination cook and dining cars, one baggage car, ten ward coaches for holding 360 recumbent or 718 sitting patients. In addition, there is one coach for the staff, one for the enlisted personnel, and one car for medical and surgical stores, with an operating and dressing room.

The preoperative train was very highly developed during the great battles at the beginning of American intervention in the late war, but toward the end, when the evacuation service was more perfected, such trains were less and less needed. These trains were filled with those who normally would have been operated upon at the Evacuation Hospital and were of a graver class of casualties than those described as slightly wounded. Careful triage, dressing, and splinting thus evacuate further to the rear a class of cases heretofore held and delayed as much or more in the operating at the Evacuation Hospital, and by so doing relieves its congestion.

Transportation from Evacuation Hospitals is under the Evacuation Officer. There are three dispositions to be made of evacuables:

(1) Those not possible to retain, and capable of being rendered fit for duty in less than four weeks, go to hospitals in the Zone of the Army. Evacuation to special army hospitals is usually by motor ambulances.

(2) Those needing more than four weeks for their treatment are sent to Base or larger hospitals, or to specialized units in the Zone of the Interior.

FIG. 25.—INTERIOR OF HOSPITAL TRAIN NO. 54, HARREVILLE, FRANCE, APRIL 26, 1918.

(3) Those fitted for duty or requiring only a few days to become so are disposed of in a more direct way, and are sent either to a Depot Division or to a Convalescent Depot or Camp.

The **sanitary trains** of the Army were such in number as might be needed to reinforce Corps and care for Army troops. These Field Hospitals and Ambulance Companies have already been described, as have the functions of evacuation ambulance companies and ambulance sections. The number of these was in proportion to the need as defined by the Chief Surgeon of the Expeditionary Forces.

Convalescent Camps and Convalescent Depots

The distinction between *convalescent camps* and *depots* is rather a fine one.

The *Convalescent Camp* is or should be near a group of hospitals, usually Base or General Hospitals, whose bed space is overtaxed. These camps take over such patients as no longer need active, routine treatment, merely medical and surgical surveillance, but who are not ready for duty. Under the stimulus of healthful, graduated exercises, military music, restful barrack life, and games and amusements, in some beautiful spot, not near enough to the lines to take away their comfort, but always within sound of the guns, they are rapidly conducted from a convalescent into a military frame of mind, and vie with one another in the effort to get back into active service. At the Convalescent Camp the plant is at heart still a hospital, and careful supervision and some special treatment are given the men.

At a *Convalescent Depot* the men are rapidly trained up, sleep in barracks, and have only a dispensary and a ward for occasional breakdowns. The developmental treatment of orthopedic conditions is best handled at a place of this sort, but both institutions, camp and depot, should be commanded and officered by medical officers; otherwise they will fail of their purpose. They are salvage depots for men, and men can only be salvaged by medical officers.

The Special Army Hospitals

These were highly developed by the French in the late war, but the change in type of warfare eliminated from our program very nearly all save the Neuropsychiatric Hospitals, Gas Hospitals, Hospitals for Infectious Diseases, Hospitals for Plastic Work on the Face and Head, and for Dental work, and Hospitals for Skin Diseases.

Each individual rest area had its camp hospital of 300 beds and was equipped to handle the routine surgery and medicine of a division in a normal state of repose or training. It was usually lodged in wooden barracks or improvised large buildings of a town, and, being undisturbed, gradually acquired an excellent routine and good equipment. These hospitals had the privilege of evacuating, generally by ambulance, into nearby Base or General Hospitals.

The **Base Hospital** was an S. O. S. unit, and when found in the Zone of the Army was there for the specific purpose of receiving the overflow and evacuable cases from Evacuation Hospitals. It was a stable unit and was equipped to handle all medical and surgical problems, differing from the base hospital of the rear only in its more elaborate triage and bathing equipment, and in the simplicity and improvisation of its quarters and methods as well as in its class of cases, which more frequently demanded primary surgery. These base hospitals were in large, improvised buildings in towns or in wooden barracks some 30 to 60 or more kilometers from the line, and at times were grouped in huge French barracks hastily renovated for their functioning.

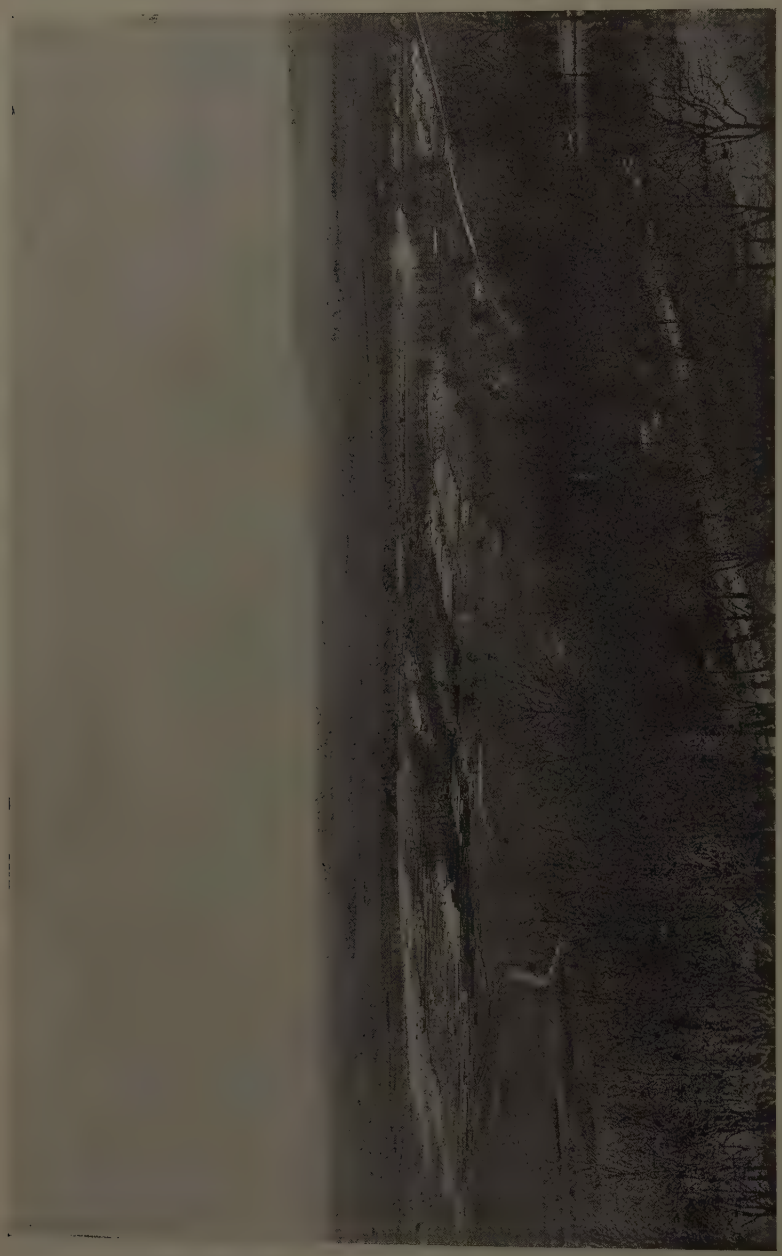


FIG. 26.—BASE HOSPITALS NOS. 53 AND 88, HAUTE MARNE, FRANCE, SHOWING TYPE OF COUNTRY AS ONE APPROACHES THE LINES.

THE FIELD SERVICE SCHOOL FOR MEDICAL OFFICERS

When not in a campaign of open warfare there should be one of these in every army, within easy motoring distance of the line. To this center should be brought all available medical officers of divisions

not actually in combat and a short ten days' or two weeks' course given by the most experienced medical officers in battle duties and the functioning of the army medical units from front to rear, always interspersed with visits to typical units and a practical demonstration of all that is taught. Not only such officers but also those who have served in the lines as well as those who serve in the rear should be brought there to contribute their information at the same time that they learn each others' special problems, the ideals of their professional leaders, and the constantly changing methods of the Medical Department in the field—changes made necessary by the progress of medicine and surgery and the development of the military situation. It is a veritable clearing house for ideas on the medical service of the army. By this combination of didactic teaching, demonstration, and example a real spirit of co-operation and mutual comprehension will be created which will bring about that *esprit de corps* and unification of the medical service that can be obtained in no other way. It is particularly useful in educating those whose duties keep them behind the lines and out of touch with the great difficulties of those who do the emergency work with the troops, as well as in curbing the well-intentioned efforts of the front line man to do more field surgery than he should.

The Chief Surgeon of the Field Forces

He is the representative of the Surgeon General in the field. He has representatives of his staff at General Headquarters of the Army if he is not there himself to maintain constant personal liaison with the Commander-in-Chief and the General Staff. In addition, certain medical officers are members of the General Staff, and every important Medical Department activity is there represented. Under the Training Branch of the General Staff is the Staff College and the Field Schools for the Army. Among these schools, which are generally located within easy reach of the lines in the Zone of the Armies, is the Army Field Service School for Medical Officers, known as the Army Sanitary School during the War, the name Sanitary being applied to cover not only sanitation but also all activities of the Medical Department. This school, like its prototypes of the army, should devote one-third of its course to didactic teaching and two-thirds to demonstration on the lines. It is, however, in the same relation to the other schools of the Field Forces as the Staff College to their subsidiary schools. To this school should be brought as lecturers the best minds and leaders in the various branches of our profession as applied to war.

Under the Chief Surgeon is also the group of Senior Consultants for the Professional Services, who should be also installed near the lines and the Army Schools in which they also should teach the policies of the Medical Department.

The Service of Supply

The Chief Surgeon of the Field Forces has his headquarters in the Service of Supply Zone. This zone is divided into an Advanced Sec-

tion and Intermediate Section, and a series of Base Sections, each with its Chief Surgeon and Staff to cover administration duties similar to those already considered for the Chief Surgeon of Armies.

The Medical Supply Depots

At the Bases are Base Storage Stations for the accumulation of medical supplies. There are also Base Medical Supply Depots for the issuing of supplies. In the Intermediate Zone is generally one large Intermediate Medical Supply Depot for issue to medical units with troops not in the line, and fixed medical units such as Base and Camp Hospitals. From this Depot the Advance Medical Supply Depot is kept stocked. Last of all and nearest the troops in the line is the Army Dump, for combatant organizations.

Sanitary Areas

The entire area of the S. O. S. is organized into Sanitary Districts, each with its inspectors, laboratories, and sanitary squads. There is also an elaborate system of railway control of which the Hospital Train Service is only a branch, but into which medical officers are incorporated.

The Attending Surgeon

In all large cities there is an Attending Surgeon with a personnel corresponding to the number of officers and men to be cared for. The service is largely a dispensary and house-to-house attendance.

Red Cross

It is in the Service of Supply that Red Cross agencies have their units and from which their activities extend toward and into the Zone of the Armies.

Camp Hospitals

For all cantonments of troops in this zone there are conveniently scattered about Camp Hospitals to which reference has been made and which do not differ materially from their prototype, the civil hospital of a town of 25,000 inhabitants. They have a personnel of 12 officers and 106 men, are equipped with two ambulances and a supply truck, and have a capacity, as has been said, of 300 beds.

The Base Hospital

The great medical unit of the Zone of the Service of Supply is the Base Hospital. It was here that the definitive surgery of war used to be done. Today a large part, not to say most, of the primary surgery is done in the Evacuation Hospitals at the front and at certain Base Hospitals near the front in the Zone of the Armies. The Base Hospitals of the Zone of the S. O. S. fulfil a mission which no other can fulfil. They provide bed capacity for the evacuable wounded as well as a reserve of operating centers. The total bed capacity of military hospitals should equal about 15 per cent. of the combatant force. The

position of base hospitals enables them to develop and practice a higher degree of specialization than those nearer the front, and each hospital should have a correspondingly high class of surgeons and internists, not to mention the specialists in civil practice. The underlying principle of a base hospital is that each one shall represent by its staff all the important branches of medicine and surgery. Here, where professional conditions are not markedly influenced by the uncertainty of battle, there need be less improvisation, and a much higher degree of thoroughness and permanency is possible. There is, however, abundant opportunity to develop the art of improvisation, especially in the adaptation of the large buildings which are usually turned over to them to be converted into the uses of a large hospital. They are by no means limited to previously constructed buildings, however, and many instances are seen in which wooden barracks or even tents supplement insufficient bed space. Here it is that men are sent for treatment extending beyond four weeks, and it is here that elaborate orthopedic apparatus must be installed. Here it is, also, that organized efforts begin to reclaim the soldier for usefulness in civil life. But we must by no means imagine that these hospitals do no primary surgery nor that they cease to be repair shops for the restitution of elements temporarily incapacitated for combat. Such is far from being the case. To these hospitals come the preoperative trains, and in the storm of great battles heavy waves of wounded fresh from the battlefield beat upon them, taxing to the limit the strength and endurance of the personnel. For this reason, again, the personnel should be as fully cognizant of front line conditions as the staff of the Evacuation Hospital, and of the principles of handling sudden in-rushes of wounded. These hospitals also have their triage, bathing, and preparation wards. Under these circumstances they differ from Evacuation Hospitals only in that they are relatively immobile and therefore can make more elaborate preparation for the refinements of medicine and surgery. But there is one difference between the Evacuation and the Base Hospital. At the former we see much less frequently the Carrel-Dakin method of handling wounds, because there "sterilization of the wound is by the knife"—to use an expression of the French—while at the latter the Carrel-Dakin technic is generally much in evidence. The reason is clear. It is never a question whether one or the other method is intrinsically the better for treating wounds; it is merely a question whether or not infection has already gained a foothold, of knowing *when* to use each method. If the wound is infected, or the anatomic lesion is inoperable, the chemical treatment of the wound is imperative if the best results are to be obtained. For a patient to reach a base hospital in the S. O. S. without previous primary operation generally presupposes infection, save in the slightly wounded, and this hospital must be prepared to combat it.

Another noticeable feature of Base Hospitals is the greatly increased importance of the bacteriologist and his laboratory, his intervention in the operating room, and his consulting opinion in the after-treatment.

Many wounds have already been cleansed of their dead tissue and liberated of lodged fragments of metal and clothing at the Evacuation Hospital, but have not been closed. Such wounds require constant and vigilant study bacteriologically, and the bacteriologist, to a large extent, should cast the deciding vote as to when to close a wound by operation. Here, also, radiology, largely limited to rapid methods of localization, blooms out in all its marvelous and valuable applications. Radiographs are made, and instrumental installation is far more complex. Here, too, is more comfort for the soldier; the relief from the anxieties of war can be made to do much in building up a shaken nervous system and an overtaxed body.

Here the special senses receive attention not possible under battle conditions, and operative procedures are undertaken which time and lack of equipment have heretofore forbidden.

But even back in the S. O. S. the ruling aim should be to get the man back to the firing line. For this and for strong economic reasons, when the time comes that he merely occupies a bed under observation in convalescence, he should be sent immediately to a convalescent camp. These camps have been described, but it is urged that wherever possible they should be frontward, away from hospital environment and atmosphere, which, after its beneficent effect has been exercised, with continuance becomes a positive detriment to the soldier, notwithstanding the good intentions of war workers of patriotic societies.

The Base Hospital in its administration is an independent military post under the command of the Commanding General; professionally it should lack little that a first-class general hospital in any of our large cities can offer. To say more than this would be trite.

There is, however, one vital warning to be given. There is more to be considered in war than the individual. Our medical education, hitherto, has been directed largely toward healing the individual. War opens up great wounds in our national body politic, and it is necessary to have men to fill them up. Only those operations, as a rule, which a man needs to enable him to do his duty should be performed. A twisted septum, enlarged tonsils, varicocele, and even a few external hemorrhoids which give no trouble had better be left for the end of the war. Otherwise, not only is a man in fighting trim and spirit held back, but a bed is occupied which a badly wounded man may need at any moment.

Hospital Centers

Hospital centers were enormous hospitalization areas in which were grouped several Base Hospitals devoted in their entirety to special classes of cases, the whole being under one administrative control—to facilitate supply and to economize transport as well as material. Such centers are, of course, huge barrack or tent constructions, but they must be well out of the way of avions and enemy thrusts. The United States Army had one of these centers in the late war, with a bed capacity of 25,000. At these centers specializing is carried to its highest degree.

Special hospitals, Post hospitals, and Hospital Ships need no detailed description, as they depend on the peculiarities of individual campaigns or are elsewhere treated.

Division of Laboratories.—The accompanying diagram describes better than words the underlying principles upon which was built the Laboratory Division of the A. E. F. during the late war. Colonel Joseph F. Siler, Medical Corps, was the Director of this service.

Portable Laboratory Equipment

Experience early in the war showed that reduction of equipment and supplies of all sorts to the absolute minimum consistent with efficiency is a vital consideration. The procurement, transportation, and automatic replenishment of supplies entailed difficulties that resulted in much delay; and many items, some of which were essential, were not available for months.

To meet this emergency Colonel George B. Foster, Jr., Medical Corps, designed a transportable laboratory in chests, in which the necessary laboratory equipment and supplies were reduced to approximately 150 items. The essentials for clinical pathology formed the contents of three chests, and these only were furnished medical units where a wider scope of work was not called for. In five additional chests were embodied the equipment and supplies necessary for the accomplishment of bacteriologic and serologic procedures. While primarily intended for mobile units solely, the shortage of regular laboratory supplies made mandatory the placing of this transportable equipment in many stationary medical units. Over 100 transportable laboratories were functioning with the A. E. F. when the Armistice was signed.

The satisfactory service that portable laboratory equipment gave in France has led to the decision that similar equipment should be assembled and stored against any emergency requiring its use with future Expeditionary Forces. Colonel Foster has recently designed an eighteen chest outfit, which, by varying the combinations of chests and by expansion in various ways, it is believed will meet the essential needs of any type of laboratory functioning with an Expeditionary Force. The equipment for the future consists of the following chests:

Chest No. 1—Glassware, chemicals, and reagents for clinical pathology.

Chest No. 2—Apparatus and equipment for clinical pathology.

Chest No. 3—Stationary and miscellaneous supplies for clinical pathology.

Chest No. 4—Incubator for bacteriology.

Chest No. 5—Autoclave for bacteriology.

Chest No. 6—Hot-air sterilizer for bacteriology.

Chest No. 7—Fuel (kerosene oil and denatured alcohol).

Chest No. 8—Apparatus for bacteriology and serology.

Chest No. 9—Chemicals, reagents, and stains for bacteriology and serology.

Chest No. 10—Glassware for bacteriology and serology.

Chest No. 11—Chlorinating apparatus for the preparation of Dakin's solution.

Chest No. 12—5-gallon bottles for Dakin's solution.

Chest No. 13—Equipment, complete, for histopathology.

Chest No. 14—Microscope and accessories for routine clinical microscopy.

Chest No. 15—Apparatus and equipment for water analysis.

Chest No. 16—Glassware, reagents, and stains for water analysis.

Chest No. 17—Venereal disease laboratory equipment, complete.

Chest No. 18—Equipment and reagents for determining the color, turbidity, and alkalinity of water and controlling its chlorination.

Crate No. 19—Folding laboratory tables.

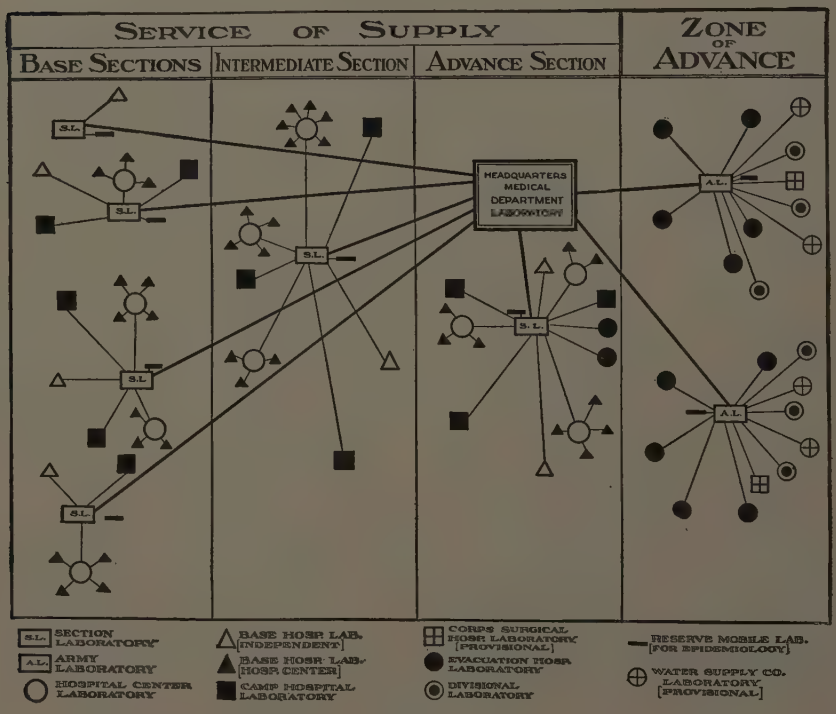


FIG. 27.

Scope of Laboratories:

1. *Headquarters Laboratory, Expeditionary Force:*

(*a*) Division of Pathology. Routine gross and histopathologic work; collection and preservation of pathologic specimens, standardization of methods and new technic; special investigation.

(*b*) Division of Bacteriology. Routine bacteriologic work. Identification of cultures sent in for confirmation; standardization, etc.; investigations.

(*c*) Division of Serology. Routine serologic work; produc-

tion and standardization of diagnostic sera, antigens, and amboceptors; standardization; special investigations.

(*d*) Division of Chemistry. Routine examination (food, water, poisons); preparation of standard solutions, reagents, etc.; standardization; special investigations.

(*e*) Division of Epidemic Diseases. Personnel for reinforcement to existing sanitary organizations in the investigation and control of epidemics.

(*f*) Division of Instruction. Inauguration of necessary courses.

(*g*) Division of Supply. Routine and special supplies; manufacture of culture-media and their distribution; distribution of stains, diagnostic sera, special reagents (amboceptors, antigens, etc.).

2. *Section Laboratories, S. O. S.:*
   - (*a*) Routine bacteriologic work.
   - (*b*) Preparation of special vaccines.
   - (*c*) Identification of cultures.
   - (*d*) Routine serologic work.
   - (*e*) Distribution of diagnostic sera, standard solutions, antigens, amboceptors, etc.
   - (*f*) Routine gross and histopathologic work.
   - (*g*) Collection and preservation of pathologic specimens.
   - (*h*) Routine chemical examinations.
   - (*i*) Manufacture of culture-media and their distribution.
   - (*j*) Distribution of laboratory animals.
   - (*k*) Special investigation.
3. *Central Laboratories for Hospital Centers:*
   For the main, as for the preceding, this laboratory supervises autopsy work for the center.
4. *Base Hospital Laboratories Operating Independently:*
   - (*a*) Routine clinicopathologic, bacteriologic, serologic, chemical, and gross histopathologic work.
   - (*b*) Wassermann and other complement fixation work.
   - (*c*) Autopsies; collection and preservation of pathologic specimens.
   - (*d*) Preparation of standard solutions, reagents, culture-media, staining solutions, etc.
   - (*e*) Special investigations.
5. *Camp Hospital Laboratories:*
   All routine clinicopathologic work and, when desirable, general bacteriology.
6. *Evacuation Hospital Laboratories:*
   - (*a*) Routine clinicopathologic work.
   - (*b*) Autopsies.
   - (*c*) Collection and preservation of pathologic specimens.
   - (*d*) General bacteriologic work.
   - (*e*) When immobilized, as a Base Hospital laboratory.

7. *Army Laboratories:*

One to each army. As Section Laboratory, save that it does not prepare vaccines or distribute laboratory animals. It presides over autopsies and has a special epidemiologic personnel for the investigation and control of epidemics.

8. *Division Laboratories:*

One to each Division:

(*a*) Routine clinicopathologic work.
(*b*) General bacteriologic work.
(*c*) Autopsy work.
(*d*) Collection and preservation of pathologic specimens.
(*e*) Bacteriologic examination of water.
(*f*) Control of chlorination.
(*g*) Epidemiologic and laboratory investigation of epidemic diseases.
(*h*) Special investigation.

In the Zone of the Interior the Surgeon General of the Army directs the entire medical establishment of the Army. Beyond the enunciation of the general policies of the Medical Department at home and with the Field Forces his function consists chiefly in the physical examination of all applicants for enlistment; the creation, organization, training, and equipment of Medical Department units; the provision of medical supplies and replacements for the Expeditionary Force; the hospitalization of all sick and injured in the Zone of the Interior; and the care, treatment, and reconstruction of the repatriated wounded. In addition to this, there is one duty which of all others is perhaps the most difficult and most heavily burdened with responsibility, the prevention of disease and the struggle to limit epidemics among troops in preparation for service with the field armies.

The professional significance of the Base Hospital is here represented by the *General Hospital.* This hospital is directly under the Surgeon General, and its scope covers all of that of the Base Hospital plus much that even a Base Hospital cannot embrace—such as the fitting of artificial limbs, the provision of a department for the reconstruction of the wounded, etc.

The multiplicity of units and of duties to solve these problems is too great to even attempt to list. Few of the men who accompany the troops when they sail away have the faintest realization of the self-sacrificing and valuable work by which their confrères make possible their achievement at arms with the colors.

For the surgical equipment and impedimenta for a Battalion Combat Unit and the various dressing stations and hospitals, see the "Supply Tables" of the American Army.

CHAPTER IX

ORGANIZATION AND ADMINISTRATION OF THE MEDICAL DEPARTMENT OF THE UNITED STATES NAVY FOR WAR*

By William Hemphill Bell, M. D., F. A. C. S.,

Captain, Medical Corps, U. S. Navy

I. Introduction.

II. Organization and Administration in General.

III. Headquarters (Navy Department and Bureau of Medicine and Surgery).

1. PHYSICAL DIVISIONS OF ORGANIZATION.

A. Personnel. Regular and Reserves:

Their numerical strength and distribution: (*a*) Medical Corps; (*b*) Dental Corps; (*c*) Hospital Corps; (*d*) Nurse Corps (Female); (*e*) Public Health Service; (*f*) Red Cross (Hospital Units); (*g*) Retired Officers.

B. Material Provisions:

(*a*) *Schools:*

Their character and distribution. For commissioned personnel: Regular—Naval Medical School, Washington; Supplementary—various medical schools with associated hospitals, to meet the demands for intensive training incident to sudden expansion. For warrant and enlisted personnel: Regular—at Newport, Great Lakes, San Francisco, and Hampton Roads; Supplementary—at various medical schools.

(*b*) *Medical Supply Depots:*

Principal establishments at Brooklyn, N. Y., Mare Island, Cal., and Canocao, P. I.; local establishments in the several Naval Districts to meet increased local demands in time of war.

(*c*) *Dispensaries:*

Character and distribution: Naval—those connected directly with different types of stations; those specially designed for general service in the several districts; United States Public Health Service Dispensaries.

(*d*) *Special Provisions:*

Accommodation at Receiving and Training Stations and camps—Laboratories (fixed and mobile); Dental pavilions (operating rooms); Psychiatric Pavilions; Sterilizer Plant, etc.

(*e*) *Hospitals:*

Character and distribution: Naval—permanent and their enlargement; temporary—Supplementary, to meet the increased demand—United States Public Health Service; civilian.

(*f*) *Hospital Ships:*

Character and equipment: Regular Government Ships ("Solace," "Mercy," and "Comfort"); private ships acting under the Navy; plans for new ships under construction for the purpose.

(*g*) *Water and Land Transportation of Disabled:*

Ambulance ships and launches, vehicles, and trains: their character and source.

2. SERVICE DIVISIONS OF ORGANIZATION.

A. Ashore.

(*a*) *Recruiting:*

As concerns Medical Department in point of physical and mental soundness; intensive re-examinations at stations receiving recruits—physical, dental, and psychiatric inspections; weeding out of unfit; physical preparation of the fit—immunization, dental work, and psychiatric determinations of capacity for special duties; organization of each.

* The publication of this chapter is authorized by the Secretary of the United States Navy and the Surgeon-General of the Navy. Supplementary to Chapter LXVII, Vol. IV, p. 1018, and Chapter CXL, Vol. VI, p. 748.

(*b*) *Training Stations and Camps, Receiving Ships, Yards, Ammunition Plants, and Bases:*
Organization and function of the Medical Department included within them.

(*c*) *Training of Medical Department Personnel for Efficient Service:*
Schooling for Medical and Dental Corps; character of curriculum and its purposes.
Schooling for Hospital Corpsmen—general preliminary training for naval service, elementary schooling for their duties in the Medical Department; advanced schooling for higher ratings, special duties and independent duty; correspondence courses for officers (reserves) and Pharmacists; service periodicals in the interest of professional refreshment and progress—Naval Medical Bulletin and Supplement (for Hospital Corps); other publications.

(*d*) *Medical Supply Depots:*
Their function in relation to the rest of the service, both as regards adequacy and quality of equipment and supplies; organization.

(*e*) *Dispensaries:*
Their function in relation to their own and other branches of the Service; organization and extent of professional work done by them.

(*f*) *Hospitals:*
Organization—the position of the types in the line of relief; convalescents of Naval Hospitals evacuated to civil hospitals; the particular use to which Public Health Service hospitals were put.

(*g*) *Naval Districts:*
Their number and general location; Medical Department organization and function in the several Districts.

(*h*) *Marine Corps:*
Naval Medical service with.

(*i*) *Naval War College:*
Naval medical representation at.

B. AFLOAT.

(*a*) *Combatant Ships:*
Principal types (submarines, destroyers, cruisers, battleships); other small combatant craft (scouts, mine-layers, sweepers, submarine chasers, etc.); character of medical provisions and service on each.

(*b*) *Ships Composing "The Train" of the Fleet:*
Medical provisions and services; medical part in the transport service, to be considered more fully later.

(*c*) *Hospital Ships:*
Physical relationship to the Fleet, organization and internal functioning.

IV. Battleship Conditions of the Present Day.
The changes noted particularly in relation to active service as they may concern the Medical Department; protection of exposed positions; gas-masks; antiflash clothing and Kapok life preservers.

1. PROVISIONS FOR THE SICK AND INJURED.
A. ACCOMMODATIONS:
(*a*) *Sick quarters—elements composing it and character of equipment.*
(*b*) *Battle Dressing Stations—location, size and type of installation, and the equipment.*
B. SUPPLIES:
(*a*) *That for time of peace (Medical Storeroom).*
(*b*) *The war reserve chest (Battle Station storerooms)—additional equipment and supplies held in readiness for emergency; items and quality of each composing it; standard wound dressings.*

2. ORGANIZATION OF MEDICAL DEPARTMENT OF BATTLESHIPS.
A. FOR ROUTINE WORK.
B. PREPARATION FOR BATTLE:
(*a*) *First-aid instruction.*
(*b*) *First-aid provision at gun and other isolated positions.*
(*c*) *Dispositions, arrangement, and supplies.*
(*d*) *First-aid dressings.*
(*e*) *Clothing (flash-proof).*
(*f*) *Protection of ears.*
(*g*) *Gas-masks.*

C. Conduct of the Medical Department During Battle:
(*a*) *Scope of relief.*
(*b*) *Disposition of wounded. Battle dressing station reports and identification tags.*
(*c*) *Transportation on board ship.*
D. Conduct of the Medical Department After Battle:
(*a*) *New ideas concerning transportation in general.*
(*b*) *New types of stretchers to meet requirements.*
(*c*) *The Stokes splint stretcher modified.*

V. Hospital Ships.
New ideas concerning the field and character of their service; not to be confounded with ambulance ships; duties in peace and war.

VI. Transports.
Navy responsible for handling ships; organization of the medical service (return of wounded and medical cases—provisions for insane).

VII. Air Service.
Heavier and lighter than air; medical organization for.

VIII. Reconstruction.
Plan and organization for.

I. INTRODUCTION

In respect to the subject matter of this chapter it should be understood at the outset that no differences may properly be admitted as between times of peace and of war, except that one is a constant, unlagging preparation for the other, offering time for comfortable changes in the adoption of improvements as personal ingenuity or the inventiveness of others suggest. Theoretically, at every figurative moment in the development of offensive and defensive preparation, readiness-to-act-efficiently is essential, for the event of war is always emergent. In this the completeness and proved practicability of an organization is vital.

Progressive improvement in and the standardization of the conditions, material and organizational, surrounding the practice of surgery are "the most practical means to advance the art and science of surgery," and this truth assumes a special dignity with reference to acute —emergency—surgery and the devices which seek to prevent or minimize the demand for it. In this connection, and in a broad sense, every arrangement of the medical departments of the fighting services in the interest of physical fitness of personnel has a surgical bearing, for the supreme test is ability to withstand the terrible forces let loose by the declaration of war.

It was believed long before our participation in the war, and no thought or effort to realize it had been spared, that all that is implied by the word "readiness" had come to be an accomplished state as far as the Medical Department of the Navy was concerned. The principles involved were considered as established and the organization was drafted and provisions made accordingly. Simple expansion of the one and enlargement of the other would alone be necessary, and for these comprehensive plans had been tentatively projected. The high service ambitions, keen professional and business perceptions, forward-looking vision, broad knowledge, resourcefulness, and untiring industry of Admiral W. C. Braisted, Surgeon-general of the Navy, gave justification for the confidence that his department would function smoothly

and nothing would be lacking when the need arose, and it was during the first three years (1914–17) of his administration subsequent to the issue of Vol. VI of this publication and leading up to and through the early stages of the catastrophe of 1914 that great strides in old and new features of the preparation for war of the Medical Department were made. The Medical Department of each of the several notable foreign navies had presumably also been thoroughly adjusted to advanced possibilities and organized and equipped along parallel lines, although with variations reflecting national peculiarities or individual ideas; but that of the United States Navy is considered to have been the most highly perfected in these respects. Many think, indeed, that the temptation to prescribe in detail has been indulged too far, but I can see naught but advantage in this, while at the same time admitting that the great events of war rarely come to pass in conformity with rehearsals.

It is, of course, a supreme obligation of "the game" ingeniously to prevent successful anticipation on the part of a theoretic or actual enemy, but it is none the less important in the process of training intelligently to conceive the various possibilities and devise to meet them with particularity. The estimate of a situation in repetition covering different problems with attendent decisions and plans of action makes for stability of integration and resourcefulness. And so with a carefully drafted program for the conduct of the Medical Department, it provides a sense of security, assures co-operation, and constitutes a substantial starting-point from which to exercise judgment and diversify conduct in obedience to the peculiar unforeseen demands of the moment, without getting too far away from the principles which should animate and guide all elements of an organization in the attainment of its mission. Emergencies are seldom well met when much is left to chance.

Many of the differences in accommodations, equipment, and organization between the Medical Departments of the United States Navy and the British Navy, for example, are explained by variations of policy and by the fact that the latter's fleet operates for the most part within small radii—the North Sea, English Channel, Mediterranean, etc.—with naval bases close at hand; whereas, the activities of the United States Navy usually involve long cruises and remoteness from large bases. In the British Navy, as a rule, none but the most trivial cases are kept on board ship, all of a communicable or operative nature being promptly transferred to hospital ship or shore hospital; whereas, the medical officers of combatant ships of the United States Navy for the above reasons are frequently called upon to care for continuously and often to their conclusion the most serious cases. This has stimulated the utmost refinement and comprehensiveness in provisions for professional work, as seen on all battleships. "Fundamentally, in so far as organization for battle is concerned, the British and American standards are much the same and the organizations are not dissimilar." Both services strive for the identical object in conformity with like

principles. The difference is in the method of approach "due to differences of personnel, equipment, and the building up of the system."

The preparedness of the Medical Department of our Navy for the complete and efficient discharge of its function at the time the United States entered the World War is notable, and distinguished credit is due the Surgeon-general for that comforting fact. The most intelligent foresight was exercised by him, and with the Congressional confidence he enjoys the expansion of organization and extensive enlargement of material resources which had been projected were possible. Practical experience with the tentative plans early indicated the need of slight modifications in some directions, but this was merely a part of the perfecting process and was not disturbing. It was thoroughly well known what would be required and how it was to be done. Men and money alone were needed.

Undoubtedly, however, the greatest possible occasion for the revision of previous tenets, whether as regards operative procedures and technic or organization in the interest of surgical effectiveness and the attainment of happiest results in military fields of practice—the Navy no less than the Army—was created by the World War.

In attempting to exhibit the organization of the Medical Department of the United States Navy as the background and mainstay of surgical preparedness, it is not without the expectation at the same time of giving adequate notion of the composition and activity of the Medical Departments of other navies in respect to corresponding features thereof and under like circumstances. It is also hoped in so doing to establish a basis for the broader acceptance of a single standard—to find acceptable common ground for both the under- and overorganized. Information has been gathered from various sources for the purpose of writing this chapter, and, in addition to the specific acknowledgment of material aid in foot-notes and the bibliography, I wish here gratefully to acknowledge the assistance obtained through personal memoranda, letters, original notes, and unpublished reports or articles from various other medical officers of the United States Navy.* Many of them served in the Sixth Battle Squadron of the Grand Fleet in the North Sea and others on destroyers or transports, or with the submarine or air service in the war zone.

Many other medical officers of the United States Navy served with the land forces at the front in France, but the character of their duties and the organization under which they worked are so inextricably concerned with the large and serious new problems of medical service with the Army that any lessons which they may have learned, although of possible application to the operation of Navy "Landing Forces," must be left for embodiment in the associated chapter which will bring the subject of Military Surgery up to date.

* I mention especially: Rear Admiral W. C. Braisted, Surgeon-General U. S. Navy; Captains F. L. Pleadwell, F. E. McCullough, J. A. Murphy; Commanders Wm. Seaman, I. S. K. Reaves, E. U. Reed, R. J. Straeton; Lieutenant-Commanders W. H. McDonell, E. H. Tennent (D.S.); Lieutenant W. H. MacWilliams.

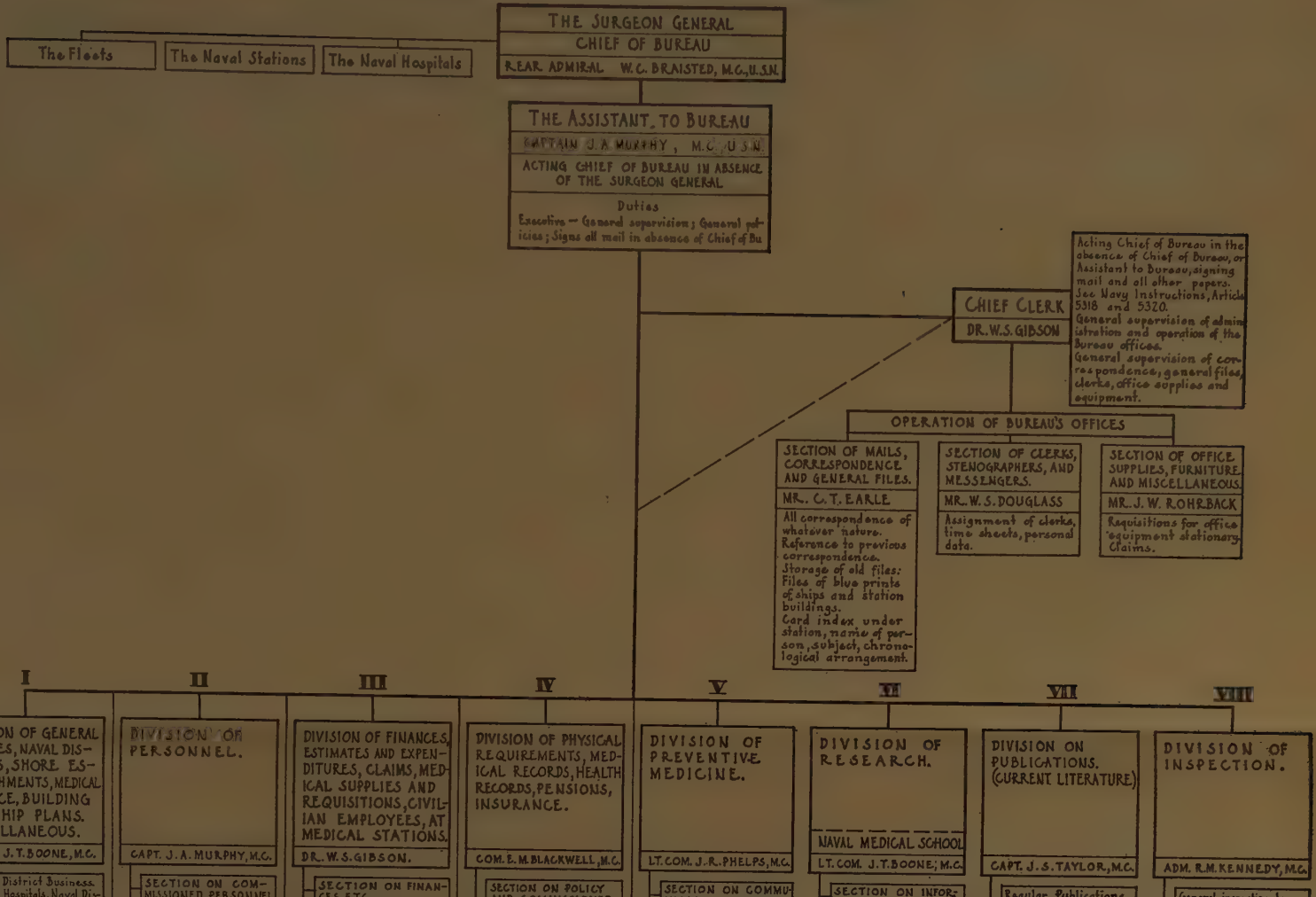
Aside from the question of organization, the experiences of the recent past suggest a number of new subdivisions of the subject in the nature of special and in some instances unexpected, though, as events proved, important fields of medical activity. These will be presented with as much brevity as may be consistent with clarity. Of course, much of this chapter will be devoted to information in modification of that contained in the chapters on Naval Surgery to be found in Vols. IV and VI, to which the reader's attention is invited.

II. ORGANIZATION AND ADMINISTRATION

"The question of 'Administration' is inextricably intertwined with that of 'Organization,' for nothing that is not organized can be administered, and nothing can be permanently organized that is not susceptible of administration. Yet the terms are not interchangeable and should not be confused. . . . In spite of this interrelation, they are terms distinguishing distinct things. . . ."[1] One of the outstanding principles which is essential to the success of administration is the recognition by the ultimate head of an organization that "areas of discretion" must be conceded. "The theory of the necessary existence of areas of discretion lies in the fact that unforeseen conditions and problems incident and collateral to the business in hand are continually arising in each branch of the work and must be met and solved without avoidable recourse to the higher administrative head. It also lies in the fact that the methods to be adopted in accomplishing a given part of a common task should ordinarily be left as far as possible in the hands of the . . . (subordinate)."[1] The operation of this principle without at all ignoring the importance of or interfering with the attainment of unity in standards explains the minor differences found throughout the Medical Department of the Navy in hospitals, at stations, and on ships, which superficially at least seem similar in their requirements. It is the resultant of indoctrination in the aims of an organization which holds the various subdivisions of it true to policy. "The interpretation of 'areas of discretion,' then, is 'the right to do *right* as . . . (the subordinate may) please'—the right to act and exercise judgment within the range of loyalty to the policy and mission and plans of the institution with which he is identified."[1] For the mere purpose of maintaining interest and inspiring initiative as well as for other important reasons, the variations which may and do appear are admissible. Indeed, they express a healthful activity and are a substantial promise of efficiency at the time of supreme test.

Nothing in this direction need be in default of compliance with the regulations, rules, or instructions of the Navy. The books embodying them " . . . represent a codification . . . of the most salient requirements in the interest of uniform action, administrative harmony, and service efficiency, but, large and comprehensive as these books apparently are, they do not and should not attempt to and could not successfully define the duties of a particular office in more detail than is necessary to indicate a course and provide a basis for co-operative

* THE BUREAU OF MEDICINE AND SURGERY *


The Fleets
The Naval Stations
The Naval Hospitals
THE SURGEON GENERAL
CHIEF OF BUREAU
REAR ADMIRAL W.C. BRAISTED, M.C., U.S.N.
THE ASSISTANT TO BUREAU
CAPTAIN J.A. MURPHY, M.C. U.S.N.
ACTING CHIEF OF BUREAU IN ABSENCE OF THE SURGEON GENERAL
Duties
Executive — General supervision; General policies; Signs all mail in absence of Chief of Bu
CHIEF CLERK
DR. W.S. GIBSON
Acting Chief of Bureau in the absence of Chief of Bureau, or Assistant to Bureau, signing mail and all other papers. See Navy Instructions, Article 5318 and 5320.
General supervision of administration and operation of the Bureau offices.
General supervision of correspondence, general files, clerks, office supplies and equipment.
OPERATION OF BUREAU'S OFFICES
SECTION OF MAILS, CORRESPONDENCE AND GENERAL FILES.
MR. C.T. EARLE
All correspondence of whatever nature.
Reference to previous correspondence.
Storage of old files: Files of blue prints of ships and station buildings.
Card index under station, name of person, subject, chronological arrangement.
SECTION OF CLERKS, STENOGRAPHERS, AND MESSENGERS.
MR. W.S. DOUGLASS
Assignment of clerks, time sheets, personal data.
SECTION OF OFFICE SUPPLIES, FURNITURE AND MISCELLANEOUS.
MR. J.W. ROHRBACK
Requisitions for office equipment stationery. Claims.
I
DIVISION OF GENERAL POLICIES, NAVAL DISTRICTS, SHORE ESTABLISHMENTS, MEDICAL SERVICE, BUILDING AND SHIP PLANS. MISCELLANEOUS.
LT. COM. J.T. BOONE, M.C.
Naval District Business. Naval Hospitals. Naval Dis
II
DIVISION OF PERSONNEL.
CAPT. J.A. MURPHY, M.C.
SECTION ON COM-
III
DIVISION OF FINANCES, ESTIMATES AND EXPENDITURES, CLAIMS, MEDICAL SUPPLIES AND REQUISITIONS, CIVILIAN EMPLOYEES, AT MEDICAL STATIONS.
DR. W.S. GIBSON.
SECTION ON FINAN-
IV
DIVISION OF PHYSICAL REQUIREMENTS, MEDICAL RECORDS, HEALTH RECORDS, PENSIONS, INSURANCE.
COM. E.M. BLACKWELL, M.C.
SECTION ON POLICY
V
DIVISION OF PREVENTIVE MEDICINE.
LT. COM. J.R. PHELPS, M.C.
SECTION ON COMMU-
VI
DIVISION OF RESEARCH.
NAVAL MEDICAL SCHOOL
LT. COM. J.T. BOONE, M.C.
SECTION ON INFOR-
VII
DIVISION ON PUBLICATIONS. (CURRENT LITERATURE)
CAPT. J.S. TAYLOR, M.C.
Regular Publications
VIII
DIVISION OF INSPECTION.
ADM. R.M. KENNEDY, M.C.

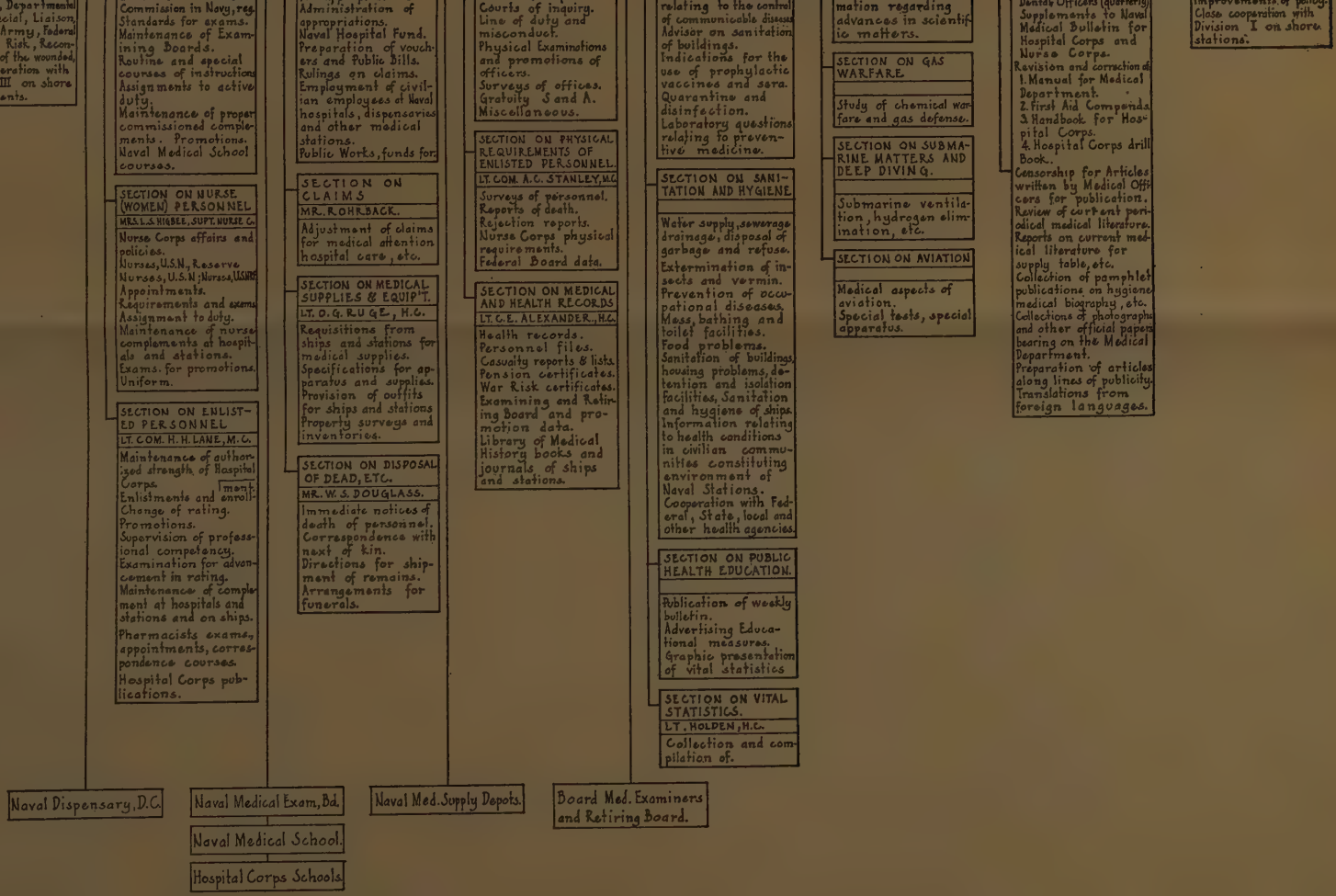

equipment, Departmental reports special, Liaison, Red Cross, Army, Federal Board, War Risk, Reconstruction of the wounded. Close cooperation with Division VIII on shore establishments.
Commission in Navy, reg. Standards for exams. Maintenance of Examining Boards. Routine and special courses of instruction. Assignments to active duty. Maintenance of proper commissioned complements. Promotions. Naval Medical School courses.
SECTION ON NURSE (WOMEN) PERSONNEL
MRS. L. S. HIGBEE, SUPT. NURSE C.
Nurse Corps affairs and policies. Nurses, U.S.N., Reserve Nurses, U.S.N.; Nurses, U.S.M.C. Appointments. Requirements and exams. Assignment to duty. Maintenance of nurse complements at hospitals and stations. Exams. for promotions. Uniform.
SECTION ON ENLISTED PERSONNEL
LT. COM. H. H. LANE, M. C.
Maintenance of authorized strength of Hospital Corps. Enlistments and enrollment. Change of rating. Promotions. Supervision of professional competency. Examination for advancement in rating. Maintenance of complement at hospitals and stations and on ships. Pharmacists exams., appointments, correspondence courses. Hospital Corps publications.
Administration of appropriations. Naval Hospital Fund. Preparation of vouchers and Public Bills. Rulings on claims. Employment of civilian employees at Naval hospitals, dispensaries and other medical stations. Public Works, funds for.
SECTION ON CLAIMS
MR. ROHRBACK.
Adjustment of claims for medical attention hospital care, etc.
SECTION ON MEDICAL SUPPLIES & EQUIP'T.
LT. O. G. RUGE, M. C.
Requisitions from ships and stations for medical supplies. Specifications for apparatus and supplies. Provision of outfits for ships and stations. Property surveys and inventories.
SECTION ON DISPOSAL OF DEAD, ETC.
MR. W. S. DOUGLASS.
Immediate notices of death of personnel. Correspondence with next of kin. Directions for shipment of remains. Arrangements for funerals.
Courts of inquiry. Line of duty and misconduct. Physical Examinations and promotions of officers. Surveys of offices. Gratuity S and A. Miscellaneous.
SECTION ON PHYSICAL REQUIREMENTS OF ENLISTED PERSONNEL.
LT. COM. A. C. STANLEY, M. C.
Surveys of personnel. Reports of death. Rejection reports. Nurse Corps physical requirements. Federal Board data.
SECTION ON MEDICAL AND HEALTH RECORDS
LT. C. E. ALEXANDER, M. C.
Health records. Personnel files. Casualty reports & lists. Pension certificates. War Risk certificates. Examining and Retiring Board and promotion data. Library of Medical History books and journals of ships and stations.
relating to the control of communicable diseases. Advisor on sanitation of buildings. Indications for the use of prophylactic vaccines and sera. Quarantine and disinfection. Laboratory questions relating to preventive medicine.
SECTION ON SANITATION AND HYGIENE
Water supply, sewerage drainage, disposal of garbage and refuse. Extermination of insects and vermin. Prevention of occupational diseases. Mess, bathing and toilet facilities. Food problems. Sanitation of buildings, housing problems, detention and isolation facilities. Sanitation and hygiene of ships. Information relating to health conditions in civilian communities constituting environment of Naval Stations. Cooperation with Federal, State, local and other health agencies.
SECTION ON PUBLIC HEALTH EDUCATION.
Publication of weekly bulletin. Advertising Educational measures. Graphic presentation of vital statistics
SECTION ON VITAL STATISTICS.
LT. HOLDEN, M. C.
Collection and compilation of.
mation regarding advances in scientific matters.
SECTION ON GAS WARFARE.
Study of chemical warfare and gas defense.
SECTION ON SUBMARINE MATTERS AND DEEP DIVING.
Submarine ventilation, hydrogen elimination, etc.
SECTION ON AVIATION
Medical aspects of aviation. Special tests, special apparatus.
Dental Officers (quarterly). Supplements to Naval Medical Bulletin for Hospital Corps and Nurse Corps. Revision and correction of: 1. Manual for Medical Department. 2. First Aid Compends. 3. Handbook for Hospital Corps. 4. Hospital Corps drill Book. Censorship for Articles written by Medical Officers for publication. Review of current periodical medical literature. Reports on current medical literature for supply table, etc. Collection of pamphlet publications on hygiene, medical biography, etc. Collections of photographs and other official papers bearing on the Medical Department. Preparation of articles along lines of publicity. Translations from foreign languages.
Improvements of pathology. Close cooperation with Division I on shore stations.
Naval Dispensary, D.C.
Naval Medical Exam. Bd.
Naval Medical School.
Hospital Corps Schools.
Naval Med. Supply Depots.
Board Med. Examiners and Retiring Board.

FIG. 28.—CHART SHOWING THE ORGANIZATION OF THE BUREAU OF MEDICINE AND SURGERY.

effort. Much is everywhere properly left to the initiative and resourcefulness of the incumbent of that office—his area of discretion—and it is by utilizing the latitude of this area for useful service to the full, quite as much as through any other means, that the possibilities of the office are rounded out, the interests of the service are advanced, and progress is made. There is no need to enumerate all or cite any one in particular of the several specific or general provisions set down, . . . for these are . . . available for reference, but . . . they are not restrictive . . . and are broad enough to admit of almost any innovation, within the scope of Medical Department activity, calculated to enhance its usefulness as a co-ordinate branch of the Navy."[2]

The body of Medical Department organization is prescribed, but the nearer the approach to the administrative head, the fewer and less flexible are the controlling regulations. It is in descending toward the terminals of organization and within the field which these represent that prescription becomes less confining and opportunity for individuality is opened, subject only to the dictates of a basic sense of loyalty and responsibility. For the features of the Medical Department organization as they will be presented in succeeding pages, therefore, universal accuracy cannot be claimed—nor is it necessary. But it can be asserted that they are faithful to the best and latest approved ideas and practices and may be accepted as thoroughly representative.

III. HEADQUARTERS

Headquarters of the Medical Department is one of the seven divisions of the Navy Department, known as Bureaus, whose functions together with those of other central departmental organizations are co-ordinated in the interest of the Navy's primary *raison d'être*—an efficient fleet, by the office of Naval Operations, the chief of which is the direct representative of the Secretary of the Navy.[3]

These several Bureaus represent departments of distinctly special work and responsibility into which Naval administration and maintenance are divided, and each devises its own organization for the duties with which it is charged.

The Bureau of Medicine and Surgery, which is the headquarters of the Medical Department, is organized as represented on the accompanying chart (Fig. 28). By the eight divisions there shown under the Surgeon-general—viz., General Policies, Personnel, Finances, Physical Requirements, Preventive Medicine, Research, Publications, and Inspections—the outlying activities of the Medical Department are severally assisted, directed, and controlled. The Surgeon-general is kept in touch with the ramifications in the field of his responsibilities by the heads of the Bureau divisions, and all orders and official correspondence passing out from them receive his consideration, sanction, and signature. Thus he is kept fully advised at all times concerning the occurrences and work and problems of his own department, and with his knowledge, through the office of Naval Operations and otherwise, concerning the activity of other departments of the Navy, he is

able to form his judgments, make administrative decisions, and reliably advise the Secretary of the Navy, to whom he has direct access.

The routing to destination of official correspondence from the Surgeon-general is shown by the following tabulation:

The Fleet.	Naval Hospitals.	Navy Yards and Stations.	Naval Districts.
To Commander in Chief (Fleet Surgeon).	To Commanding Officer.	To Commandant or Commanding Officer (Senior Medical Officer).	To Commandant (Medical Aide).
To Division or Force Commander (Division or Force Surgeon).			To Commanding Officers of different activities (Medical Officer).
To Commanding Officer of Ship (Senior Medical Officer).			

It is to be observed as suggested above by the Surgeon-general's direct address to the Commanding Officer of Hospitals that these institutions come immediately under his supervision and control. This is also true of other elements of his department as indicated by the chart of organization, such as Naval Dispensary, D. C., various examining Boards, Naval Medical Supply Depots, Naval Medical Schools, and Hospital Corps Schools.

1. Physical Divisions of Organization

A. **Personnel.**—The personnel of the Medical Department is divided into (*a*) Medical Corps; (*b*) Dental Corps; (*c*) Hospital Corps, and (*d*) Nurse Corps (Female) as permanent and regular factors—each with a reserve element recruited among the civilian population to a strength unlimited legally, which is drawn upon in case of national need. Under this heading also appear the personnel resources represented by (*e*) the U. S. Public Health Service and (*f*) The Red Cross, both of which, as permanent institutions, are potential factors of great usefulness to the Navy, but only temporary in their official relation to it during the continuance of war. An additional supply of officers exists to a limited extent in those retired for disabilities which do not incapacitate for recruiting and other physically light duty.

The United States Public Health Service is strictly limited in respect to available personnel in the direct and exclusive interest of medico-naval activities, but what is lacking in quantity is compensated by quality, and it is from this source that the Navy through wise arrangements by the Surgeon-general draws expert sanitary advisers in time of great emergency and for large problems, who, for the time being, to all intents and purposes, become an integral part of the organization of the Medical Department of the Navy.

The Red Cross, besides the extra military personnel included in its general contribution to navy weal, undertakes to recruit nurses to the

extent required who are enrolled in the navy and come entirely under and are assigned to stations and duties by the Medical Department of the Navy.

The nature of (*a*), (*b*), and (*d*) are self-explanatory and need no comment. Suffice it to say that their numbers are apportioned to the total strength of the Navy whatever that may be at any time, and that they are distributed in deference to the need of the particular type of services indicated by their classification. The Medical Officer is, of course, everywhere; the Dental Officer is stationed at dispensaries and hospitals, on battleships, and on hospital ships; and the nurse is assigned to dispensary, hospital, and hospital ship duty.

The Hospital Corps is composed of the enlisted men and warrant and chief warrant officers (Pharmacists) of the Medical Department, the lower ratings constituting the male nurse element and the upper enlisted ratings and warrant grades the special and independent duty element in the composition of the Corps. It was indicated above that the members of the Medical Corps were ubiquitous, but this is more exactly the case with the Hospital Corps, for wherever there is a medical officer there is a hospital corpsman, but there are many substations and ships in the Navy without medical officers on which the sole representative of the Medical Department is a hospital corpsman, and relatively few places, indeed, lack such representation.

In addition to the individual enrolment of reserves for general service, the Naval Reserve Force, including Medical Officers, dental officers, nurses, hospital corpsmen, and other enlisted men of different ratings is now in various cities throughout the country organized into groups, known as "Naval Base Hospital Units" and "Naval Station Hospital Units."[4] Each of these "Units"* constitutes a complete staff representing the diversified and special talent required for the efficient conduct of a large or small hospital, as the case may be, and stands ready as such to take up its duties whenever needed. The constituent elements and the numerical strength of the two different units are prescribed by the Medical Department of the Navy, and each upon being ordered to active status is to be headed by and come under the command of a medical officer of the regular service for duty within this country or on foreign territory as circumstances require.

The policy in the organization of these units, as at first conceived, is to favor the grouping of individuals belonging to the same institution or at least community, in the interest of preserving the force of local *esprit de corps*, "without which these 'units' would tend to disintegrate in peace times," and by which successful team work may be assured and immediately realized. Of course, the first and important desideratum in such organizations is the central figure or director, whose selection and appointment is a prerequisite. He "must not only personify the very highest mental, moral, and professional standards, but be himself a leader of men who . . . (can) inspire enthusiasm and create a following. . . ."

* The term "Unit" embraces both personnel and equipment.

The complement of the "Naval Base Hospital Unit" is as follows:

Two medical officers* (commanding officer and executive surgeon); 18 medical officers; 1 pay officer; 1 dental officer; 60 nurses; 1 pay clerk; 1 commissary steward; 1 chief yeoman; 4 yeoman, second or third class; 2 carpenter's mates, third class; 2 electricians (general) third class; 2 plumbers and fitters; 80 hospital apprentices, first and second class; 2 coxswains or machinist's mates, second class, for chauffeurs or mechanicians; 1 cook, first class; 4 cooks, second class; 8 cooks, third or fourth class; 20 mess attendants; 1 pharmacist*; 2 chief pharmacist's mates*, 3 pharmacist's mates,* first class; and 4 pharmacist's mates,* third class.

The complement of the "Naval Station Hospital Unit" is as follows:

One director (who may be chief of either the medical or surgical section) with the rank of Lieutenant-Commander; 1 chief of medical (or surgical) section, with the rank of Lieutenant-Commander; 1 specialist, eye, ear, nose, and throat, with the rank of Lieutenant; 1 specialist, *x*-ray, with the rank of Lieutenant; 20 nurses, one of whom will act as head nurse until the unit is called into service; 1 commissary steward; 1 chief yeoman (man or woman); 4 yeomen, second or third class (men or women); 2 carpenter's mates; 2 electricians (general); 2 plumbers and fitters; 2 coxswains or machinists, second class, for chauffeurs or mechanicians; 1 cook, first class; 4 cooks, third or fourth class; 10 mess attendants.

The latter is a type of unit designed with a view to drawing as lightly as possible upon the civil profession and to supply in part the personnel for the emergency hospitals erected at various naval stations to care for the rapidly expanding naval personnel incident to war. The required additions to the staff are to be furnished by the Surgeon-General from among the young officers already enrolled in the Naval Reserve Force.

B. **Material Provisions.**—Although navies in general, our own included, are commonly said to be always on a "war footing," and while this is true in the sense that all or a certain portion of the fighting units could, at any given moment, engage in battle, the statement obviously omits from consideration the well-known fact that enormous expansion of the personnel will occur coincident with or immediately subsequent to the outbreak of hostilities. It is furthermore apparent that such expansion must take place with great rapidity and concurrently comes the insistent demand for proportionate material provision of all sorts. Not the least of these are medical department facilities, and if nothing has been done—no arrangements made before the outbreak of the war—serious embarrassment will be experienced in keeping pace with the increasing demand. Indeed, material provisions should not wait upon the urgency of need, but be made in anticipation, and, as far as the controlling view of the public's representatives can be persuaded, the extent of construction and the amount of equipment and supplies should be reasonably in excess of peace requirements.

The foresight of the Bureau of Medicine and Surgery in this direction is not deficient, but its practical exercise is limited. Of course, surveys of useful outside resources in accommodations, equipment, and supplies are kept up to date; ways and means are devised for meeting

* Assigned to Unit by Bureau of Medicine and Surgery.

different inevitable or problematic situations; and plans are drafted for new construction and the remodeling of old—all against the time when funds will certainly be available so that actual expansion to meet any need may be started without delay. The Red Cross is a utilized valuable accessory source of all kinds of equipment and supplies, which can be provided expeditiously, as well as of personnel, and is of assistance in organization and in supplying trained hands for the manufacture of dressings.

(*a*) **Schools.**—The training of personnel is, of course, a matter of great importance, and the need is fully met under less than the extraordinary conditions which obtained in preparation for the recent war by the regular schools of the Navy, correspondence courses, and the medium for instruction represented by various medical department publications.

FIG. 29.—PHARMACIST'S MATE SCHOOL, HAMPTON ROADS, VA.

The former consist, for medical officers,* of the Naval Medical School located in Washington, D. C., and, for hospital corpsmen, of training-schools located at San Francisco, Cal., Newport, R. I., Great Lakes, Ill., and Naval Operating Base, Hampton Roads, Va. The school at Hampton Roads, Va., is especially prepared to instruct men of the higher ratings of the Hospital Corps including the warrant grades of Pharmacist and Chief Pharmacist.† The Nurse Corps (Female) is recruited from graduate nurses, but upon entering the service the chief nurse of groups of reserves and as many others as possible are, pending

* A Correspondence School for Medical Reserve Corps Officers is located at Washington, D. C.

† A Correspondence School for Pharmacists is also conducted at Washington, D. C.

regular assignment, sent to Naval Hospitals for temporary duty in order that they may be schooled in and become thoroughly acquainted with Naval methods and procedures.

The equipment of all the schools is absolutely modern and complete within the curriculum followed. The school at Hampton Roads is for advanced training, and its equipment is elaborate, as its function to be mentioned later will suggest.

The publications above mentioned which are such a valuable asset in the dissemination of knowledge in the interest of highest standards of efficiency consist of the *Naval Medical Bulletin* and *The Supplement to the Naval Medical Bulletin*—both issued quarterly—and the *Bulletin*

FIG. 30.—PHARMACEUTICAL LABORATORY, PHARMACIST'S MATE SCHOOL, HAMPTON ROADS, VA.

of the Division of Preventive Medicine, issued monthly. In addition to these periodicals, the Bureau of Medicine and Surgery prepares and revises from time to time manuals, compends, and drill books for the use of Medical Officers and of the Hospital Corps.

To enlarge the facilities for training medical and dental officers and hospital corpsmen in case of national emergency without extending existing government provisions unduly beyond ordinary requirements, the leading medical, dental, and pharmaceutical colleges of the country have placed their facilities at the government's disposition, and many of these were active to the great benefit of the Navy in preparation for the late war. It is regretted that space does not admit their enumeration by name. The special courses and general instructions offered

by them are conducted largely or entirely by Naval Reserve Officers included in the faculties.

(*b*) **Medical Supply Depots.**—The permanent establishments are at Brooklyn, N. Y., Naval Operating Base, Hampton Roads, Va.,* Mare Island, Cal., and Canacao, P. I. The principal depot is that at Brooklyn, N. Y. These depots supply, respectively, the Atlantic Coast and Fleet, Pacific Coast and Fleet, and Asiatic Station and Fleet. During

FIG. 31.—NEW NAVAL MEDICAL SUPPLY DEPOT, BROOKLYN, N. Y. (From U. S. Naval Medical Bulletin.)

war local establishments are opened temporarily in the various naval districts under the direction of district Medical Aides to meet the increase of local minor and urgent requirements for medical supplies, and to relieve the permanent depots of handling a large number of small shipments when freight facilities are overtaxed. This provision also permits the permanent depots to concentrate on the procurement of equipment and supplies from manufacturers and to handle the many large requisitions from large stations, hospitals, and ships. To facilitate the

* This is a subsidiary depot.

distribution of stores to naval elements operating remote from the above storing points branch depots, when possible, are established adjacent to such fields, as was done during the recent war in both France (Brest) and England (Liverpool).

The temporary branch depots are accommodated or established in such buildings or spaces as may be available in the particular locality at the time the emergency need for them arises, and their equipment is largely improvised, but the permanent ones have this uniform characteristic that they are constructed for the purpose, and are, therefore, arranged and equipped in the manner necessary for the economic and safe storage of all varieties of articles, including those requiring special care, and for the easy and expeditious receipt, storing, assembling, packing, and delivery of heavy shipments. That at Brooklyn is the main depot, and there physical, chemical, and research laboratories are

FIG. 32.—CHEMICAL LABORATORY, NAVAL MEDICAL SUPPLY DEPOT, BROOKLYN, N. Y. (From U. S. Naval Medical Bulletin.)

maintained[5] to test and ascertain that the various supplies furnished fully meet the contract specifications which are based on service requirements.

(*c*) **Dispensaries.**—These are accommodations for medical department work which need not be located so specifically. Indeed, it would be impossible to do so even if desirable because of limited space, for there are literally hundreds of them. In general, it may be said that they are located wherever naval activities ashore are found and are typical of the out-patient provisions made at all naval camps, stations, yards, rifle ranges, munition plants, and bases, etc. In addition to those identified directly with some definite naval command, there is a general dispensary especially provided for by congressional appropriation at Washington, D. C., and other special ones exist for the care of native populations, as at Guam, Samoa, and the Virgin Islands, the

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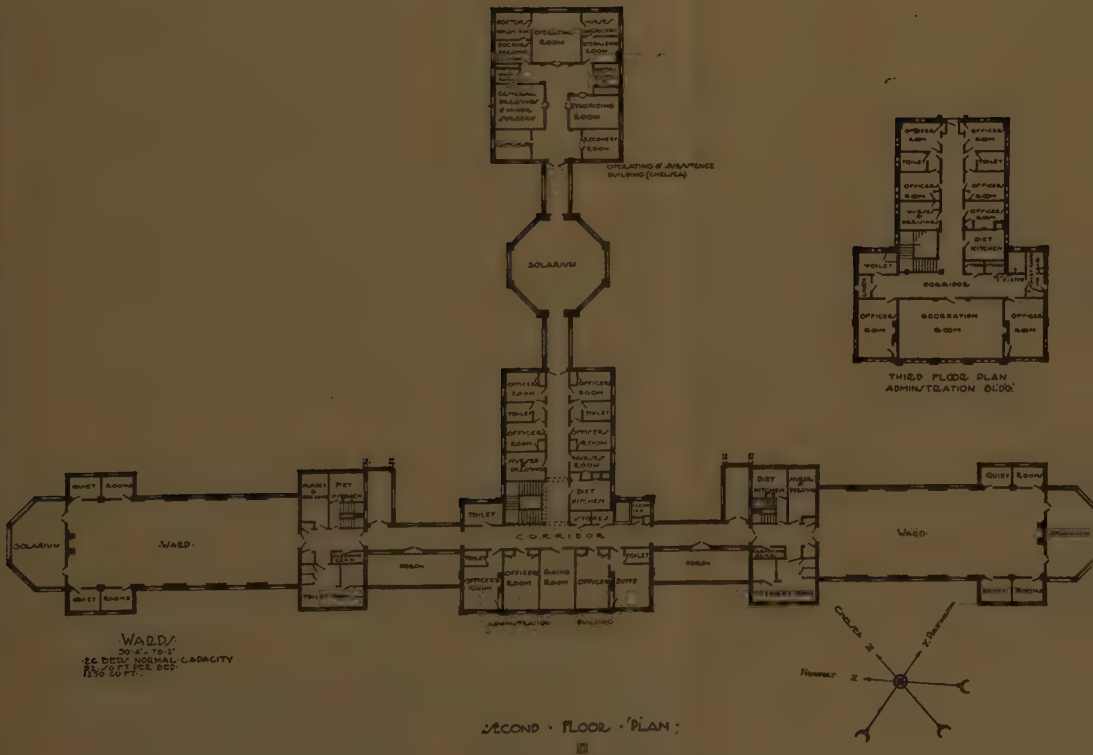
NEW UNITED STATES NAVAL HOSPITALS A

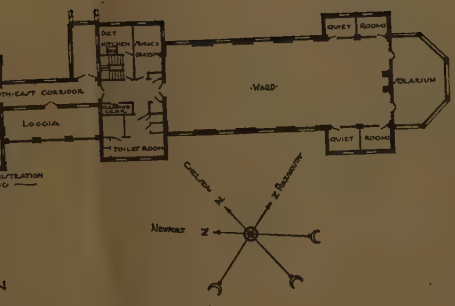


SECOND FLOOR PLAN

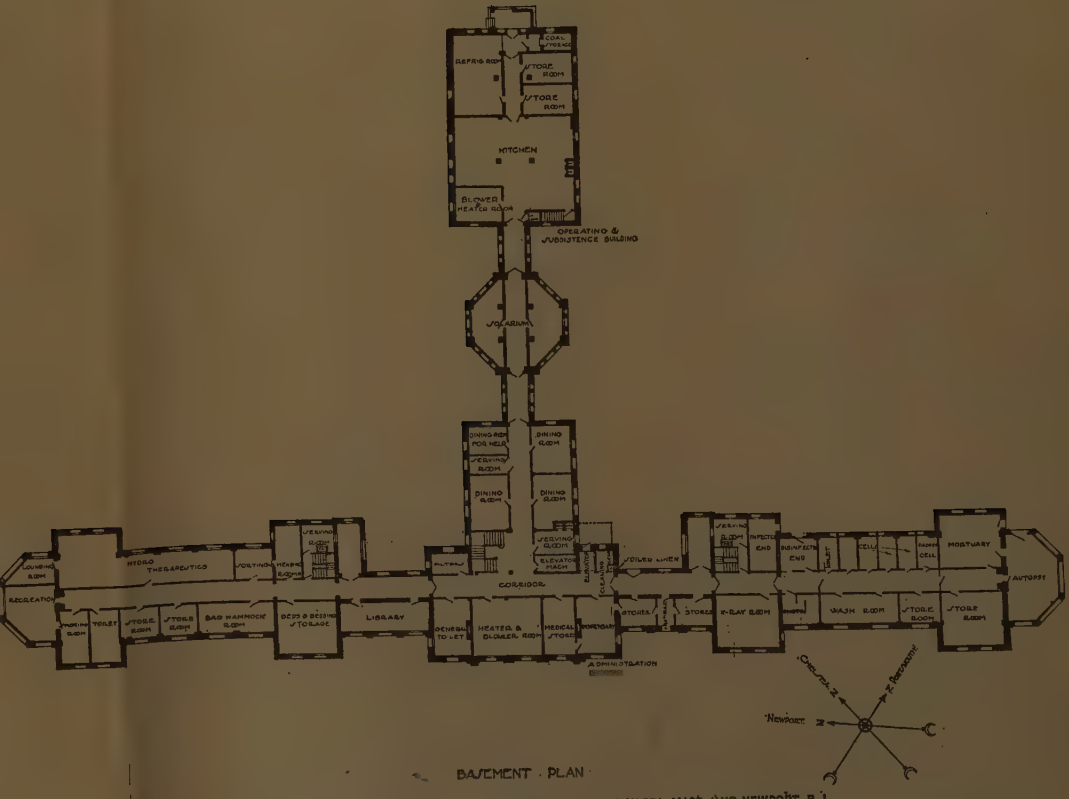
ADMINISTRATION BUILDING.
THIRD FLOOR PLAN

NEW UNITED STATES NAVAL HOSPITALS AT PORTSMOUTH, N. H., CHELSEA, MASS., AND NEWPORT, R. I.

FIG. 33.—PLAN



CHELSEA, MASS., AND NEWPORT, R. I.



BASEMENT PLAN

NEW UNITED STATES NAVAL HOSPITALS AT PORTSMOUTH, N. H., CHELSEA, MASS., AND NEWPORT, R. I.

VAL HOSPITAL.

government of which comes under the Navy Department. In the emergency of war, as may be required in consequence of the increase of personnel, other temporary dispensaries are opened and maintained in the various naval districts under the direction of the district Medical Aide. Also dispensaries may be set up in foreign countries (if allies) where Navy units are engaged. Finally, by special arrangements the dispensaries of the United States Public Health Service including their personnel are placed at the disposition of the Medical Department of the Navy for such purposes as may develop their need.

There is no one type of structure for the accommodation of dispensary work except that built in connection with the creation of the large Training Stations and to meet their well-known requirements and problems. It is a group consisting of a dispensary proper and an annexed "isolation cubicle." In other places the design of arrangement and capacity are in accordance with the particular kind of service to be rendered—*i. e.*, the reasonable expectation of emergency, the number of personnel or population to be served, and the proximity or remoteness of standard hospital accommodations.

The equipment of all of these dispensaries is in keeping with their function and in every way up to modern standards, and this is true not for the moment alone, but all of the time, for, as progress is made along this line, the Navy dispensaries participate in the benefits and improved service to be derived. Where hospital accommodations are at a considerable distance, a ward is incorporated in the plans to care for the probable percentage of bed cases until they can be transferred.

(*d*) **Special Provisions.**—These consist of large, splendidly designed clinical laboratories of modern equipment,* psychiatric observation units, dental operating pavilions, and sterilizer plants located at all of the receiving and training stations. Similar clothing and bedding sterilizer plants are also located at Navy Yards. In addition to the fixed laboratories, mobile laboratories, consisting of personnel and equipment—all ready for immediate dispatch—are available for use at camps or other temporary and uncompleted rendezvous. The psychiatric equipment includes devices to assist in determining fitness for special branches of the service in which mental alertness and agility and promptness of reactions are required.

(*e*) **Hospitals.**—Naval Hospitals are maintained usually at or in the immediate vicinity of Navy Yards and Stations, the exceptions being that at Fort Lyon, Col., and that at Yokohama, Japan. The large permanent hospitals are located at Portsmouth, N. H., Chelsea, Mass., Newport, R. I., New York, N. Y., Philadelphia, Pa., Annapolis, Md., Washington, D. C., Norfolk, Va., Great Lakes, Ill., Fort Lyon, Col., Mare Island, Cal., Puget Sound, Wash., Pearl Harbor, H. I., and Canacao, P. I. The small permanent hospital is represented by those at points of lesser naval activity, as well as in some of our minor overseas possessions, such as Guam, Samoa, and the Virgin Islands. In

* By arrangement between the Surgeon-General of the Navy and Public Health Service the laboratories of the latter are always ready to serve the Navy.

general, they vary in size and bed capacity in direct proportion to the naval population of the district they are meant to serve plus the consideration of probable demands in relation to their strategic location in time of war. In deference to these determining factors, the New York and Norfolk hospitals are normally the largest, and the total hospital bed capacity of the United States Navy before the late war was 3239. That of the east coast hospitals north of Hatteras was 1887. In time of war, of course, not only are the regular hospitals expanded by light

FIG. 34.—CHART OF U. S. NAVAL HOSPITAL RESERVATION, CHELSEA, MASS., SHOWING INTERESTING CONTRAST BETWEEN THE OLD AND THE NEW REQUIREMENTS IN HOSPITAL ACCOMMODATIONS. THE PATIENT CAPACITY OF THE OLD IS REPRESENTED BY BUILDING NO. 11.

construction, but new temporary naval hospitals are built or established in adaptable existing buildings at points indicated by medico-naval strategic considerations. During the late war, therefore, in addition to those at the above-mentioned localities and including the smaller regular institutions, the Navy had hospitals at New London, Conn., Pelham Bay Park, N. Y., League Island, Pa., Naval Operating Base, Hampton Roads, Va., Charleston, S. C., Key West, Fla., Pensacola, Fla., Gulfport, Miss., New Orleans, La., and Cavite, P. I. Naval Hospitals were also established in France and England, and

hospitals of the United States Public Health Service and numerous civilian hospitals in this country were made available for naval personnel serving in their neighborhood. In anticipation of a state of war the Bureau of Medicine and Surgery had not only prepared plans to enlarge regular naval hospitals and for new hospitals, but had made and tabulated the results of a careful survey of the seaboard civil hospitals for naval purposes. These last named hospitals, however, for various reasons were very little used. As evidence of the expansion accomplished in strictly naval hospitals, it is interesting to note in comparison with the above figure that when the Armistice was signed the total hospital bed capacity was 15,361; that of the east coast hospitals north of Hatteras was 9442. This does not include the bed capacity of dispensaries, which is a very considerable figure.

The equipment of all naval hospitals is complete and modern to the last word. Nothing is lacking that the latest methods suggest for the efficient treatment and care of the sick.

(*f*) **Hospital Ships.**—The chapters on Naval Surgery in Vols. IV and VI of this system present charts and discussions of then existing hospital ships and of what at the time were considered ideal plans. Allowing for marked improvement in detailed interior arrangement and equipment over the years that had elapsed, the outbreak of the World War found the Medical Department still dependent upon the makeshift transformed merchantman, and its ambition for a hospital ship built as such from the keel up still ungratified. The "Solace" was in commission attending the Atlantic Fleet, and unsatisfactory as she was from the point of view of perfection, she was nevertheless a splendid and serviceable ship, and rendering fine service. She was the only active hospital ship in the Navy, but other ships of merchantman type had been officially selected for conversion against the time when they would be indispensable, and complete plans had been drafted for this purpose and were on file. It is in this direction also that the Medical Department exercises foresight as a duty of vital importance. Two of the ships thus marked for hospital ship purposes, should the need arise, were taken over at the outbreak of the war and remodeled without delay in accordance with the plans, becoming the "Mercy" and "Comfort" of the United States Navy. But the Surgeon-General had not abandoned the cherished idea of building a hospital ship, and new plans along revised lines were prepared under his direction in March, 1913, and recommended by the General Board of the Navy. In July, 1914 Blackwell[6] said of these plans:

"The hull will be steel, and the ship will be an oil burner with turbine engines, twin screws, a sustained speed of 14 knots per hour and a cruising radius of about 10,000 miles. It will have five decks above the water line, so the wards and living spaces will be high above the water, with an abundance of light and natural ventilation under ordinary conditions. It will have sufficient beam, will be roomy, and, with the heavy weights placed below and the ship properly ballasted, it should be very comfortable, steady, and seaworthy. Turbine engines will do away with the unnecessary noise and vibration of the machinery and oil fuel will make it easy to keep the ship clean and sanitary, and do away with all the disagreeable features of coaling ship."

The failure of Congress at that time to authorize and make appropriation for the construction of such an auxiliary to the fleet gave further opportunity to revise the plans, and the justification for this was the weight of fresh experience in the first years of the war. This work was presented by Blackwell[7] in July, 1918, "after over eight years' close study of the subject and five years of practical work and experience on a hospital ship under varying conditions of active service with the fleet."

Congress had now for the first time (1917) authorized and appropriated for the construction of a hospital ship and the need to crystallize all ideas for the benefit of the architect and to work with him in the preparation and completion of final plans was urgent. Under the direction of the Surgeon-General, Commander R. C. Holcomb, Medical Corps, United States Navy, had more to do with the matter at this stage than any other, and he was finally given entire charge of it. It is to him that credit is due for the splendid plans herewith published as United States Naval Hospital Ship No. 1, and now in process of being given physical interpretation on the ways at League Island. It will be commissioned as the U. S. S. RELIEF. The delay of construction work on it was due to the greater need during the war for small types of naval ships of the combatant class and the employment of available labor and yards to the exclusion of all large types. It is pertinent to the consideration of this matter that while the various other naval powers, like the United States, have heretofore largely if not entirely satisfied their needs in this respect by converting merchant vessels,* *the United States, as far as known, is the first nation to "lay down" a ship of this kind.* It is understood that the British Admiralty has authorized the construction of one of these ships, but it is a question whether or not it is actually "on the ways." The United States Hospital Ship No. 1 is nearing completion.

Like the United States, other maritime nations also definitely select merchantmen suitable for the purpose and project plans for their transformation into ambulance ships† and hospital ships in advance of hostilities. During the time these are being made ready, although with the forethought indicated this can be accomplished in a short time, something must be available in substitution to meet a possible military necessity, and the British use large well-equipped passenger steamers, called Hospital Carriers, for the immediate requirements of the fleet, since active naval operations may and often do initiate hostilities. Some quite similar expedient is resorted to by Germany, and it may be said to represent a simple resource of which every country would

* The French are said to have built the "Annamite" as a hospital ship in 1877 and others of her class later (Dr. Oudard, Staff Surgeon of the French Navy), but Barthelemy says of England's decision to construct a hospital ship (Military Records of Feb. 14, 1912), "This will be the first ship in the world constructed entirely for this purpose." In Vol. VI it was noted: "Two hospital ships have been laid down in England recently, it is understood, for the Royal Navy," but I am reliably advised that, even if projected, these ships were not built.

† These are variously designated "Hospital Transports,"[8] "Auxiliary Hospital Ships,"[9] "Hospital Carriers," and "Sanitary Ships," etc.

take advantage. The need of this means of tiding over an emergency is partly obviated as far as the United States is concerned by the fact that the hospital ship has won its place by hard and efficient work as an indispensable element in the organization of the fleet. Indeed, a hospital ship has been in existence and serving with the fleet to all intents and purposes ever since the momentous days of 1908, when President Roosevelt directed the employment of the *Relief* under the command of a naval medical officer.

In accordance with the provisions of the second Hague conference government hospital ships designated by a green strake may be and usually are supplemented by those contributed by benevolent societies or private individuals, and these are designated by a red strake, but they come immediately under and, besides the Geneva flag, carry the national flag of the country served. Such ships were employed by practically every country during the late war.

It is hardly necessary to occupy space with a tedious review of the accommodations for administration, professional work and patients, and the endless items of equipment on hospital ships. One differs more or less from another in the matter of arrangement, as might be expected from the present necessity that each must be adapted from a merchant vessel, but the number and type of patients and professional work to be accomplished, the equipment to be installed, and the supplies to be provided is all pretty well standardized as a result of years of experience. The British "consider that the best vessel for a converted hospital ship is an 'intermediate' one of from 6000 to 7000 tons, which normally carries both passengers and freight." This comports fairly accurately with opinion on this side of the water. "Such a steamer is more easily converted and rearranged, and more economically managed after being put in service."

A hospital ship is assimilated to a hospital ashore, and as a means to a clear understanding of its real nature it is commonly characterized a "floating hospital," but the remodeling of a ship for hospital purposes under the circumstances of impending or actual war and with a demand for the least delay in completion leaves much to be desired in respect to possibilities. It is in the *construction* of a hospital ship that the full possibilities may be realized, and yet it is a very different problem from that of the construction of a hospital. There is just so much space within the limits of the hull and deck houses, and this must be employed to best advantage in the interest of each requirement in order of importance. "The designer must have a broad perspective and not be prejudiced in favor of one branch or specialty in medicine or surgery to the detriment of another," and thus influenced to partiality in the allotment of space. A hospital ship performing its proper function with the fleet "generally has a large out-patient clientele, but at least three-fourths of its work is on patients regularly admitted to the sick list of the ship, so the comfort, care, and treatment of those on board should be the first consideration."[7]

Space does not admit of a detailed description of the internal ar-

rangements and equipment of the United States Hospital Ship *Relief*. For this information, except as briefly shown below, the reader must consult the plans. It is sufficient to note that in the preparation of the plans the services and the duties required of a hospital ship were considered from every standpoint, and nothing practicable that would better the comfort, care, treatment, and contentment of patients or ship's personnel was omitted.

Holcomb, R. C., writes: "The Hospital Ship 'Relief' is to be a vessel of 9750 tons, normal displacement, 483 feet, 10 inches in length over all; twin screw propulsion and oil burner. When completed she should have a full patient capacity, all berths double banked, of five hundred beds with a normal capacity, with beds in acute service wards single-banked, of three hundred and eighty-seven beds. The ship is designed to carry a complement of medical officers, female nurses and hospital corpsmen, in addition to the regular crew.

"Being an oil burner, she should be free from the dirt and dust which results from periodic coaling, and in order to promote her steadiness the design includes the installation of a gyro-stabilizer.

"In external appearance she will be painted in accordance with the provisions of the Geneva Convention for military Hospital Ships, that is to say, she will be painted white with a broad green strake along her hull. She will also carry on her funnel and the top of her pilot house a Red Cross, which may be illuminated at night, designating to either a ship on the horizon or an aëroplane overhead the neutral character of her employment.

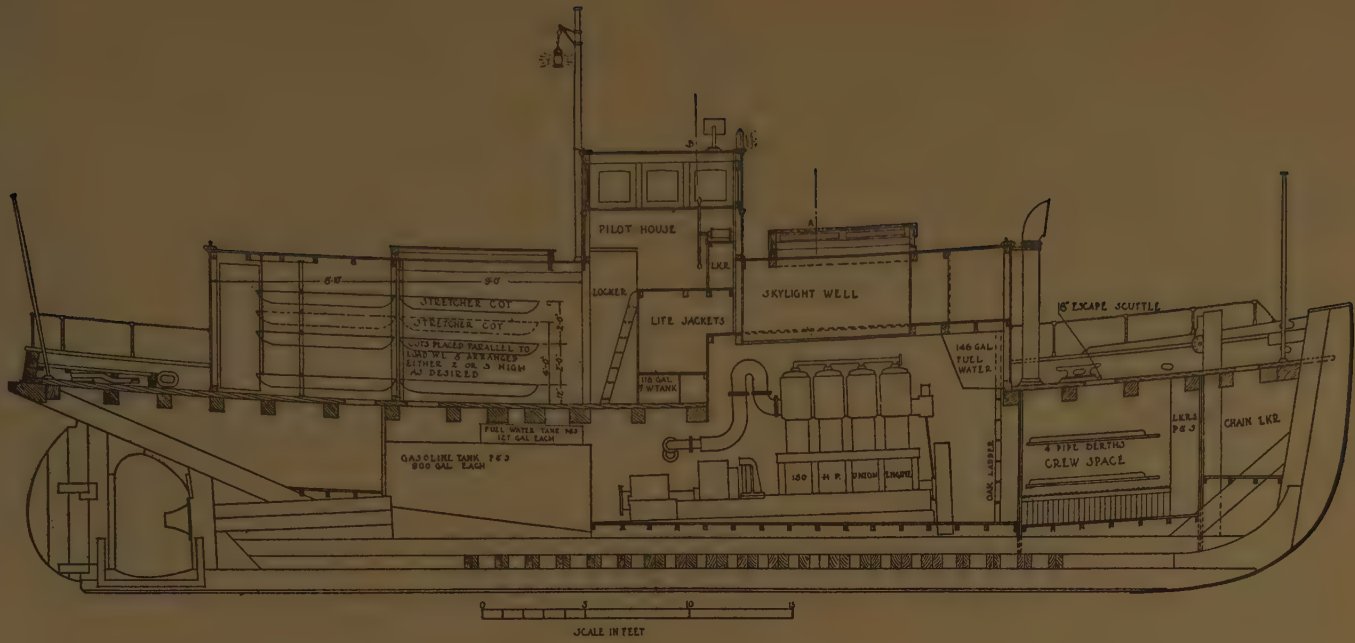
"In hospital characteristics she has been designed to meet the requirements of the fleet for the treatment of hospital cases, and also for the treatment of out-patients. The fleet must be likened to a large city of perhaps 30,000 persons, embarked in an unsteady habitation, exposed to the elements at sea and to the hazards of work about machinery and mechanical contrivances of various kinds. In her hold she will carry a complete hospital field equipment, so that her services may be of use in connection with fleet landing parties, or in attendance upon any big catastrophe, such as a tidal-wave, an earthquake, a volcano eruption, or a severe and devastating fire in a large coast city. Every effort has been made to design a ship that would meet the requirements of hospital service afloat in time of war and in time of peace.

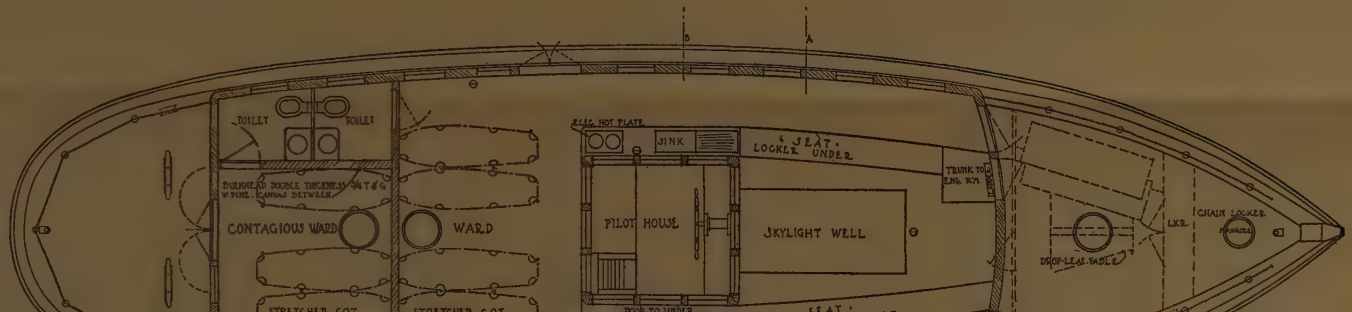
"The sick are distributed over four different deck levels and every effort has been made to promote access for patient distribution. There are three passenger elevators on the ship which will promote the transfer of patients from the wards to the special hospital rooms, such as operating room, *x*-ray room, endoscopic room, hydrotherapeutic room, etc.

"The *out-patient department* is located on the main deck adjacent to the gangways, and includes an eye, ear, nose, and throat department, dental department, *x*-ray department, and laboratory department. These departments offer co-operative diagnositc and treatment facilities to the medical officers on the ship and in the fleet. . . . Other special rooms perhaps more properly used in connection with hospital cases are not so conveniently located to the gangway, but are nevertheless available for co-operative diagnosis and co-operative treatment.

"On the *superstructure* deck are located the quarters of the Commanding Officer, the Master, some of the Auxiliary Officers, some of the Medical Officers, and all of the female nurses. The decks of the superstructures are commodious.

"The *upper deck* contains the operating suite, rooms for sick officer patients, and the rooms for the officers of the staff attached to the vessel. The operating suite consists of a sterilizing room, scrub-up room, etherizing room, and operating rooms. Every effort has been made to make this a most complete group. Special attention has been given to the matter of natural and artificial illumination, and also to the most advanced methods of heating and ventilation, these problems all presenting special difficulties in connection with the ship's construction. On the after part of the upper deck, away from the other cases and accessible only by elevator so that communication may be entirely under control, is located the contagious disease department. This consists of four wards, the largest of which contains twenty-four beds. Every effort has been made to make isolation here as complete as possible. Facilities are at hand for the disinfecting of utensils and equipment; also for the special cleansing of patients when they are discharged to duty and ready to leave the ship.


PILOT HOUSE
LKR.
LOCKER
SKYLIGHT WELL
LIFE JACKETS
STRETCHER COT
STRETCHER COT
COTS PLACED PARALLEL TO LOAD WL & ARRANGED EITHER 2 OR 3 HIGH AS DESIRED
118 GAL. W TANK
146 GAL. FUEL WATER
15" ESCAPE SCUTTLE
FUEL WATER TANK NO 2 157 GAL EACH
GASOLINE TANK P&S 800 GAL EACH
180 H.P. ENGINE
OAK LADDER
4 SIDE BERTHS CREW SPACE
LKRS P&S
CHAIN LKR
SCALE IN FEET


TOILET
TOILET
BULKHEAD DOUBLE THICKNESS MATS W PIKE CANVAS BETWEEN
CONTAGIOUS WARD
WARD
ELEC. HOT PLATE
SINK
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TRUNK TO ENG. RM
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SKYLIGHT WELL
LKR.
CHAIN LOCKER
DROP-LEAF TABLE

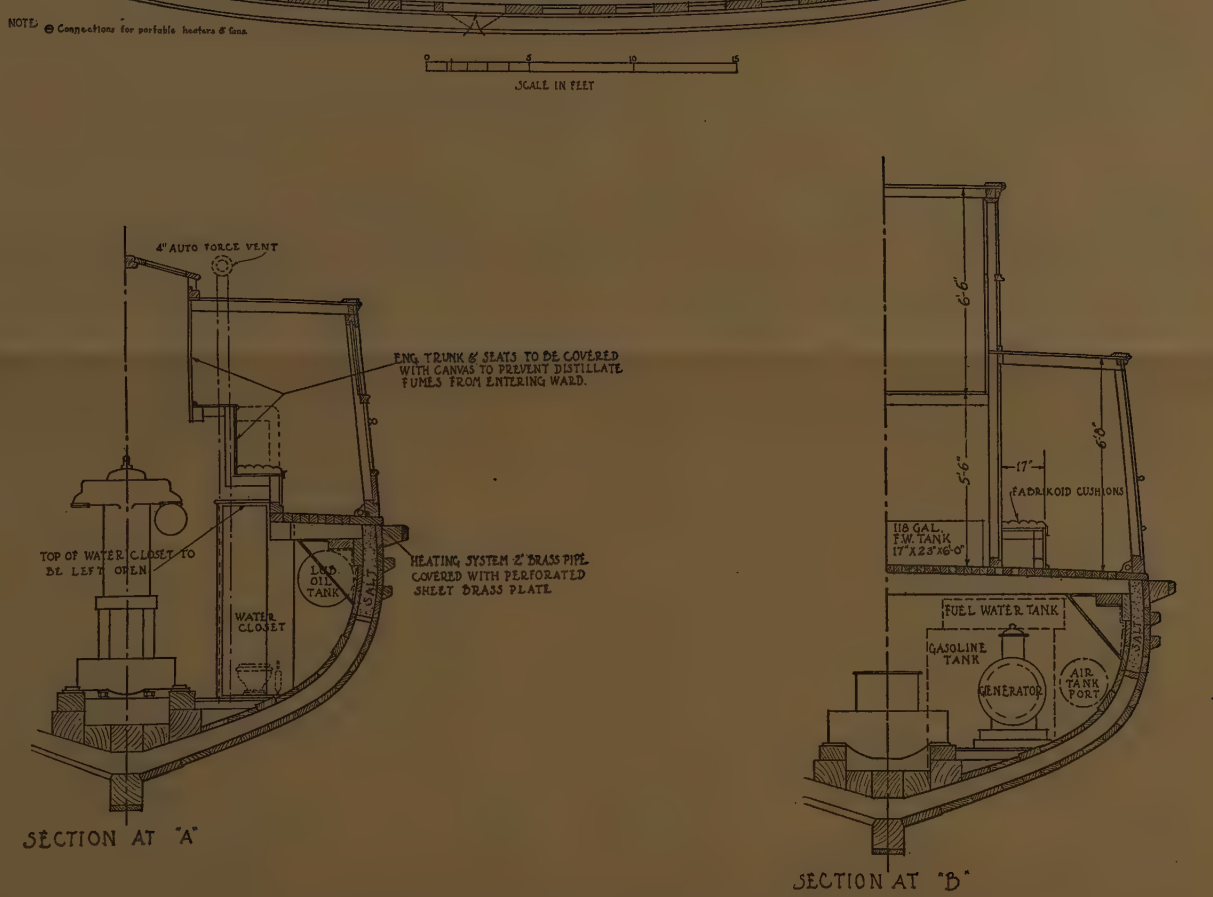


FIG. 36.—CHART OF NEW AMBULANCE BOAT (CONVERTED 65 FOOT MOTOR TUG), UNITED STATES NAVY.

"On the main deck are located the various administrative offices.

"There are special rooms in connection with the out-patient department, the galleys, commissary room; rooms for sick warrant officers, auxiliary officers of the crew, special mess rooms for venereal patients, and, well aft, the autopsy and embalming room, the disinfector and incinerator. On this main deck also, at convenient points, are located gear for hoisting patients over the side in stretchers. Gangways approaching the deck are extra wide with a minimum of steepness so as to provide easy access for patients in stretchers.

"On the second deck are located the main wards. There are special wards for treatment of medical, surgical, and venereal patients; an acute ward service supplied with quiet rooms, pantries, toilets, linen rooms, dressing rooms, and other necessary accessory rooms. On this deck there are also located the endoscopic room, hydrotherapeutic room, acute treatment rooms, diet kitchen, and such general utilities as ship's store, post office, etc.

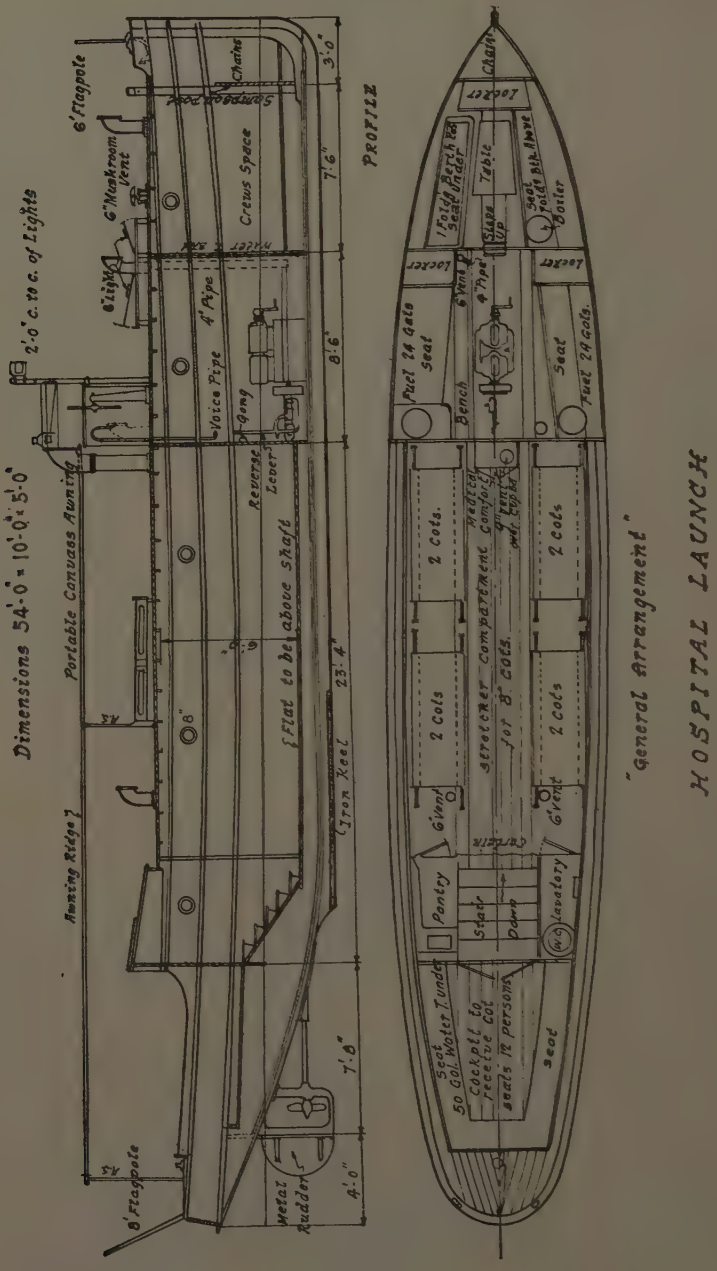
"On the first platform there are three more wards, called convalescent wards, yet so complete that the other patients may easily be handled.

"There is a large cold storage department for the carrying of meats, vegetables, fruits, and various other foods which must be preserved by some form of refrigeration. The cold storage facilities are contained on three separate platforms, the lowest and most remote of which contains a dead room for the preserving of remains until they can be transported home for delivery to the next of kin. Special facilities have been provided for the reception and handling of baggage so as to permit easy access thereto."

(*g*) **Water and Land Transportation.**—The question of water transportation for the disabled has been so improperly bound up with that of hospital ships in the past that it might well have been considered under that heading if this chapter was a history, for they were much used as ambulance ships by all parties in the late war. Indeed, it is said of the British that "all (hospital) ships employed in the channel service may properly be designated 'Ambulance Ships' while so employed. Their sick are usually on board less than twenty-four hours and their elaborate equipment is but seldom more than partially used." In our own Navy hospital ships have been used for ambulance service sufficiently to have effected a realization of the impropriety of confusing the two types of service, and to have clarified our understanding of the function of the hospital ship as distinct from the ambulance ship. It was only partially realized at the time of writing for Vol. VI of this system.

The hospital ship cannot at once efficiently serve the fleet at its base or in its movements and be away from it conveying the accumulated disabled to base hospitals[10]; it cannot at once efficiently play the rôle of base hospital to land forces on foreign soil and be off transporting the disabled to home ports[11]; it cannot escape the accusation of wasteful employment and misapplication of facilities when performing the functions of mere transportation, albeit those transported are in need of professional attention. Clearly, ambulance ships of adequate tonnage with respect to the character of the particular duty to be performed by them, are a requirement for perfected medico-naval service.* Reference is here made to ships capable of transporting large numbers between the fleet or hospital ship and the base hospital or of promptly relieving a battle-torn ship of her burden of wounded; and not to the small craft with a capacity limited to the normal number of hospital

* Unpublished paper by Captain N. J. Blackwood, Medical Corps, U. S. Navy.



cases for transfer from a ship in ordinary times. Experience has demonstrated that ambulance ships should be as much an integral part of the fleet as the hospital ship, and in its absence, the hospital ship must perform its function. If a privately equipped hospital ship is

present this duty usually falls to its lot, for, as a rule, it is smaller and less thoroughly equipped than a government hospital ship and can more easily and with less sacrifice be spared for the work.

Ambulance boats or launches are, however, maintained at ports where naval hospitals are located and at which naval vessels are accustomed to arrive. They simply collect patients from the various ships in port or arriving, and transport them to hospitals on shore and are equipped only to render first aid *en route*. Depending upon the size of the harbor and the likelihood of rough seas in the area of its operation the seaworthiness of such a launch would be a consideration in its design, if it is to be constructed, or in its selection if drawn from among the many boats common to all harbors. As in the case of a hospital ship, a launch or boat *built* for the purpose is more satisfactory,

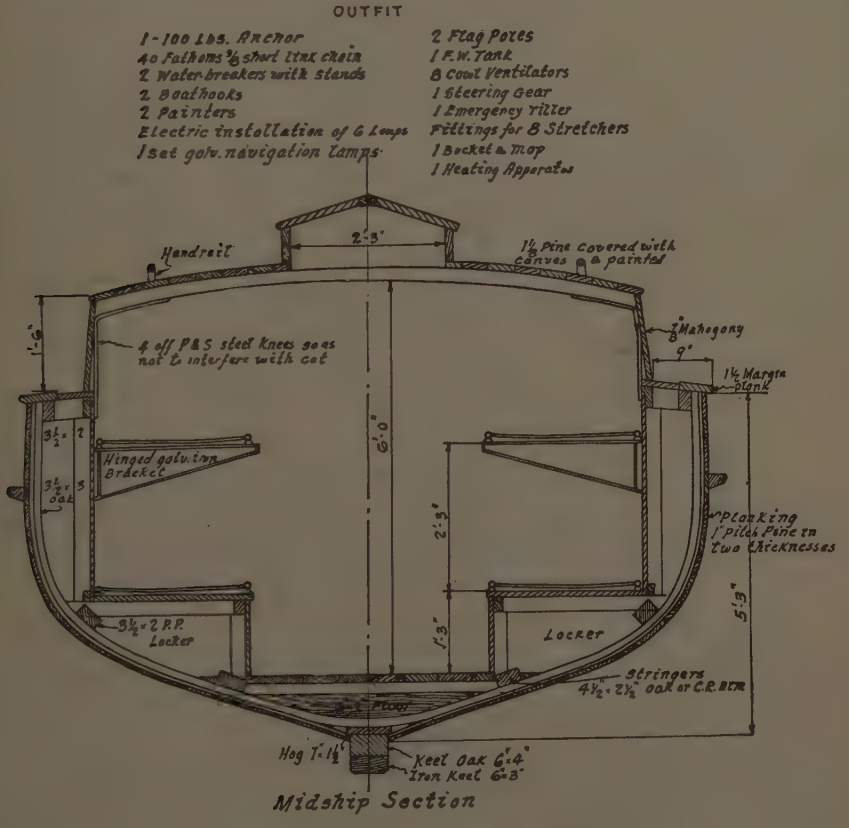


FIG. 37.—DETAILED PLAN OF "NEW HOSPITAL LAUNCH 'LANARKSHIRE.'" (From Shipbuilding and Shipping Record, Jan. 4, 1917.)

and among the many suggestions on record two types have been selected for illustration. Both are excellent and each serves slightly different requirements. The first type is represented by the converted 65-foot

motor tug of the United States Navy* and by the "New Hospital Launch"† which is an English conception. Each of these is of staunch design and seaworthy proportions which make it useful to cover greater distances and in more open waters, such as river transportation and relief in roadsteads. Both can, however, be used interchangeably with the "Ambulance Motor Boat"‡ (Blackwell),[12] representing the second

* The illustration shows the details of this tug converted into an ambulance boat. It includes separate compartments for ordinary and contagious cases, is roomy, and has a long cruising radius.

† Shipbuilding and Shipping Record, Jan. 4, 1917.

"This vessel, which measures 54 feet over all, with a beam of 10 feet and a molded depth of 5 feet, is completely decked in and equipped for open sea service.

"The planking is of pitch pine on the double-skin principle, and the hull is subdivided with water-tight bulkheads. Amidship is a stretcher compartment, some 18 feet, 6 inches in length, where accommodation is provided for eight cots, the latter being arranged in double tier. There is a commodious cockpit aft, 8 feet, 6 inches in length, arranged to receive cots from the lowering gear on the hospital ship, while there is a broad stair giving easy access to the hospital. Between the cockpit and the hospital compartment, pantry has been arranged on the port side with a fresh water-supply, and a toilet room on the starboard side.

"The hospital is heated by hot water pipe arrangement, connected with a paraffin fuel boiler in the forecastle, the pipes being run along below the upper cots to return beneath the lower ones on both sides of the vessel. Light and air are provided by ventilating ports and a large skylight, also by a 9-inch ventilator at the fore end and two 6-inch ventilators at the after end. Between this compartment and the forecastle is the engine-room, measuring 8 feet, 6 inches in length.

"The propelling machinery consists of a 64 B. H. P.; four-cylinder White & Poppe paraffin engine, which develops its power at 1100 r. p. m. No reverse gear is fitted, the MacLaren reversible propeller beng preferred by the owners. The engine is fitted with a petrol-starting device, in order that the vessel can be got under way at a moment's notice. A large supply of paraffin is arranged aft in a tank under the cockpit floor, from which the fuel is pumped to two 24-gallon running tanks, arranged on the after bulkhead of the engine space. The engine-room is complete in itself, and has its own entrance by a hatch on the weather deck. The remaining forward part of the boat is given over to the forecastle, where cots, etc., are fitted for a crew of two.

"Like the engine-room, the forecastle has its own entrance by a hinged hatch. Effective provision has been made for complete currents of air to pass through the forecastle engine-room and hospital, while special attention has been given to the draining of the bilges between the bulkhead.

"The steering wheel is situated on the weather deck directly above the engine-room, communicating with the engineer through a speaking-tube and by a gong. A stout teak dodger, some 3 feet, 3 inches in height, provides protection to the steersman. The plans of the Lanarkshire were revised and approved by the Admirality authorities before the work was put in hand."

‡ "The dimensions of the boat should be about as follows: Beam, 8 feet; depth about 5 feet, draft about 2½ feet. The cockpit for patients and other passengers is situated amidship, which is the most comfortable location for them, the coxswain's quarters just forward, and the motor machinery space just aft of it, all of which are surrounded by a hatch coaming about 6 inches high. The boat is decked over fore and aft and on each side up to the hatch coaming. The coxswain's quarters, cockpit and machinery space are covered with ordinary canvas canopy on a pipe frame, which is simple and inexpensive.

"The cockpit is 18 feet long and 6 feet wide. It has benches extending along each side and across both ends for patients and passengers. Two movable bars extend across the cockpit on a level with the top of the benches about 5 feet from the forward and after bulkheads. On these two bars and the forward and after end benches 6 stretcher patients (3 forward and 3 aft) can be comfortably accommodated. On top of the hatch coaming are four more bars across the cockpit, one 3 feet and one 5 feet from the forward hatch coaming and one 3 feet and one 5 feet from the aft hatch coaming. On these bars 6 more stretcher patients (3 forward and 3 aft) can be comfortably accommodated, giving a total of 12 stretcher patients that can be carried at one time, besides 5 or 6 ambulant cases that could sit on the

FIG. 38.—BLACKWELL'S AMBULANCE MOTOR BOAT. (From U. S. Naval Medical Bulletin.)

benches between the forward and aft tiers of stretchers. The stretchers would be fastened to the cross-bars to keep them steady and in place. If only the forward and aft part of the cockpit were filled with stretcher cases, the boat would have a capacity of 6 stretcher patients and 18 ambulant cases, or if there were not stretcher patients, the boat would have a capacity of about 30 patients. Between the forward and aft tiers of stretchers there will be a 4-foot gangway, in which the stretchers can be handled and the patients cared for.

"The umbrella canopy is simple and inexpensive and affords ample protection against all kinds of weather. On each side of the canopy at the coxswain's quarters, the cockpit, and machinery space there should be openings with canvas flaps to afford ingress to and egress from those spaces. The canopy should be divided in the middle over the cockpit, and the forward and aft flaps laced or buttoned together.

"The stanchions of the pipe frame forward and aft of the openings in the canopy to the cockpit should be hinged at the deck, or made to slide fore and aft so that the top of the canopy could be opened up in order that patients might be hoisted out with cranes, or their transference from the boat otherwise facilitated. It would be practicable to have extension tops for the cockpit, such as are used on automobiles, which could be shipped or unshipped, as desired."

type, which seems better adapted for the relatively smooth water of closed harbors. All such craft are intended to transport the sick and wounded between combatant ships and hospital ships or hospitals and between other points in a manner conducive to their best interests. Some day construction along these worthy lines will replace the makeshifts that have been depended upon in the past.

Transportation on land involves that from the simplest form by the various ingenious methods devised for a single man as carrier to specially constructed hospital trains. None of these is too trifling for serious consideration as the wonderful and dramatic record of saving lives at the front during the late war, in which transportation played such an important and conspicuous part, testifies.[13] Innumerable methods may be passed by as appertaining essentially to land warfare, and therefore a subject belonging to another chapter. Hand transportation of some kind and under varying degrees and types of difficulties is, however, an unavoidable link between the place of disablement (whether ship or battlefield) and the particular form of land transportation available or selected as a means to place the sick and wounded under the most favorable conditions in an expeditious manner.

The Navy, of course, participates in the employment of the horse- and motor-power vehicle (ambulance), though the latter has all but supplanted the former. They are similar to those used by civil institutions, but less ornate and more commodious, with no sacrifice of comfort or efficiency.

The hospital train is employed by the Navy, but occasion for doing so on this side of the Atlantic during the war did not arise—nor would it be necessary unless actual hostilities were brought to our shores (Atlantic or Pacific) making the use of ambulance ships impossible, for practically all the Navy's hospital facilities are in or near seaport towns. Evacuation from one hospital to another on the same coast is accomplished by ship. In England, however, the United States Navy used a hospital train, and in doing so handled its patients according to the method adopted by the Royal Navy, which is "based on the use of what is known as 'the canvas carrying cot,' "* which requires that hospital ships, ambulance trains, and ambulances shall be especially fitted to accommodate the cots. The British have adopted an admirable system† of handling the sick and wounded of their Navy from one unit

* "The cot consists of a rectangular wooden frame, 5 feet, 9 inches long by 2 feet, 4 inches wide, with canvas bottom, sides and ends, containing a mattress and pillow and arranged to hang from eyelets fitted into each canvas end. A completely equipped cot includes also mattress and pillow covers and two blankets. The elasticity of the canvas bottom beneath the mattress makes this cot a comfortable bed. By the use of the two blankets and by folding in the canvas sides over the patient, he may be kept warm in the coldest weather while being transported. This is considered to be of the utmost importance in handling the deeply shocked cases so prevalent among naval wounded."[14]

† "The Medical Department of the British Navy has created a special land transport organization for the removal of the wounded from the points at which they may be landed. . . . From the time a wounded man is landed from a ship until he is placed in hospital he is in charge of the land medical transport" (The Modern Hospital, November, 1917).

to another along the line of communication by means of these cots which insures the least possible disturbance of the patient and the utmost comfort with all that that means in favor of hopeful prognosis. In brief, it contemplates that the patient shall not be removed from the cot once he has been put in it until he has reached his destination via hospital ship, ambulance train and ambulance, and been transferred to hospital bed. "The Royal Navy ambulance trains are fitted with hooks to hang these cots in two tiers, the cots being prevented from swaying while *en route* by" a simple device, and the "ambulances are fitted with bodies arranged to carry four of these cots at one time." The transfer from one unit to another in the line of communication is attended by an interchange of a complete empty cot for each laden cot,

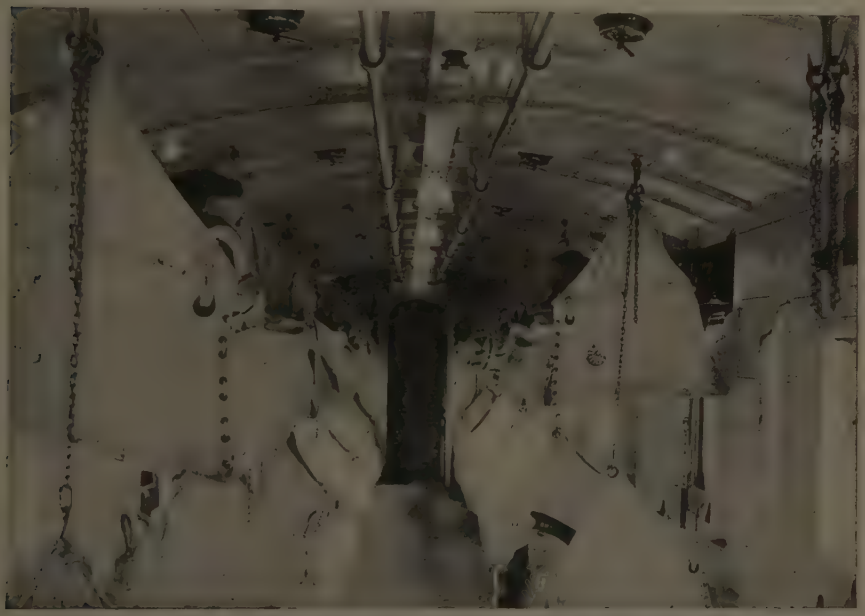


FIG. 39.—INTERIOR OF COT CAR OF BRITISH NAVAL AMBULANCE TRAIN SIMILAR TO THAT USED BY THE MEDICAL DEPARTMENT OF THE U. S. NAVY IN ENGLAND AND SCOTLAND. (From the Supplement, U. S. Naval Medical Bulletin.)

and thus every unit has at all times its allotted number of cots and is entirely ready for action. "In order to fit our Navy to co-operate with the British Navy in this method of transporting wounded, each battleship . . . (was) supplied with 25, each mine-laying vessel with 12, and each first-line hospital with 200 of these cots."

2. SERVICE DIVISION OF ORGANIZATION

A. **Ashore.**—(*a*) **Recruiting.**—The Medical Department is not only the watchdog at the threshold of the service in the interest of the physical and mental soundness of personnel, but the agency by which varieties and various degrees of minor defects within the range of acceptability for the service are promptly corrected. It is thus that the Gov-

ernment is saved avoidable expense and the Navy both embarrassment and needless deprivations in seeking man power. Enough was said in Vol. VI concerning recruiting in general to express the responsible nature of the duty, but the process of checking the work of recruiting stations,* weeding out the unfit who passed the sieve of first instance, and toning up the fundamentally physical and mental normal has not been discussed. I want particularly to bring out the less obvious factors in the close inspection and careful grooming which each recruit separately receives immediately he arrives at a "receiving ship" or training station. Having passed the examiner at the recruiting station and been enlisted, it is by no means certain that he is anything more than very temporarily in the service. The vast majority, of course, remain, and these are carried through a hard period of adjustment to their new life, of intensive observation and examination, of immunization, and of corrective treatment. The organization brings all specialties to bear and harmonizes their forces through the Senior Medical Officer.

In this connection too little has been said of the dental attention which the recruit receives and the benefits from it which accrue to the individual and to the Navy. The deplorable condition of the mouths of most of the young men coming into the Navy speaks ill for the extent of decent respect for the most primary and obvious hygienic measure—that of merely keeping the mouth clean. It is not that destructive processes are often far advanced or extensive—such a state of affairs would operate to exclude the subject of them; but that ignorance and neglect is rapidly preparing the day of distress and disability, for nothing is more subtle in its deleterious influence upon general health than deficient and diseased dentures. Practically all are rescued from this result under the interested and intelligent determination of the Navy's dental surgeon to confer dental fitness and to assist toward its permanency by instruction in oral hygiene.

The new arrival, among the initial steps in his reception, is subjected to a dental survey, and it is then that his mouth is charted and his specific needs indicated. The wholly unfit are at this time marked for elimination from the service. From the dental examining office in the receiving building this record is sent to the dental infirmary, where it is placed in open file as a memorandum against that individual. During the next few days, as soon as he has been given a fixed billet and is available, the recruit is summoned for initial treatment, and from then on until the required work is completed he is kept under the cognizance of a dental surgeon. The initial treatment is prophylactic and this may be of any degree from the simple scaling and polishing of teeth or treatment of gums to root amputations, the extraction of impacted teeth, and curetment of necrotic areas, etc.

No constructive dental work is done until the mouth is thoroughly prepared and a sense of confidence entertained that future repairs will have a solid foundation. In addition to this fair beginning offered the

* During the rush of recruiting, upon our entrance into the late war, civil hospitals were of great assistance in making special examinations for recruiting stations.

recruit, services are available to meet the dental needs of both officers and men as they arise in the course of service. At least the Medical Department is organized to do so, and thus generally successful effort is made to keep the personnel dentally fit.

The dental corps is professionally prepared and equipped with completely furnished operating rooms to do oral and plastic surgery, but there has been relatively little call for it in the Navy during the war. The corps co-operation with hospital work is very intimate, and fractures and focal infections are the cases usually turned over to the care of the dental surgeon.

Psychiatry, happily from the point of view of efficiency, has come to occupy a place of extreme importance—its rightful place—among the determined necessary inspections, examinations, and provisions which enter into the elaborate program of the preparation for and conduct of war. Great Britain and European countries led in recognizing that psychiatry had certain special applications to the military service, but the United States, at the instance of Dr. W. A. White, soon followed their example, and on or about 1908 assigned officers for special study along this line. This was a humble beginning which came to full fruition at the outbreak of the late war and resulted in the great saving and enhanced efficiency prophesied by the advocates of a more intensive and thorough and scientific effort not only in the direction of weeding out the manifest mentally unfit, but in the vastly more difficult task, for the same purpose, of determining the potential psychopath and enabling the authorities "to better adjust the individual to the specific things that will be demanded of him," more especially under the stress of war conditions.

Whether this be in operating the huge guns, submarine craft, or air machines with their complicated mechanisms and with the required precision; or "whether we consider the soldier in the trench or the sailor on shipboard, good intelligence is absolutely essential, both for the conserving of the life of the individual and the accomplishment of his task, as well as for the safety of the whole group who may be dependent upon the individual. . . ." One cannot believe otherwise in face of the "thousands of positions that are called subordinate, but which nevertheless carry considerable responsibility."[15] "The game of war is primarily a game for brains, and . . . no matter how important muscle and brawn may be, they are only, after all, means to the utilization of brains and not an end in themselves."*

The aim, therefore, in the psychiatric organization which has been built up is the elimination of the actual and potential defective as far as possible before he passes beyond the reach of the trained observer into general service where, especially on a ship, he would not only be useless, but a source of positive danger, probably requiring the attention of other men who might better be occupied in other ways.

* White (W. A.): The Application of Psychiatry to Certain Military Problems. Lecture delivered at the Summer Conference, 1913, United States Naval War College.

The problem involved is to be able to foretell how a given human being will act under certain stimuli, to discover those who though apparently normal under ordinary circumstances would certainly break down under the extraordinary circumstances of war which cannot be artificially reproduced for the purpose in view with anything like a close simulation of the tremendous waves of emotion experienced by the individual as a result of exposure to the horrors of actual warfare.

"Roughly speaking, one may divide the types of cases to be weeded out of the service into three great classes, namely, (1) the feeble-minded, including constitutional inferiors; (2) psychoses, actual and potential; (3) functional and organic nervous diseases. In other words, the cases to be looked for comprise not only defective intellectual processes existing from birth or from an early age, but also cases of disordered thinking coexistent with mature intellect, such as the insanities and the functional types, as well as cases of organic lesions of the central nervous system.

"Obviously, the matter of weeding out such unfit subjects cannot be left to methods of casual observation and personal judgment. Naturally, a frank case of insanity, for example, would not require specialized methods to detect it. But (military services naturally attract certain types of mental defectives) the cases which present themselves . . . are, as a rule, border-line types of all kinds, and only careful and detailed examinations will bring their defects to light.

"Perhaps the greatest difficulty lies in discovering the higher types of feeble-mindedness, such as morons and high-grade imbeciles. These cannot be identified by inspection. Many of them have a fluent command of language and possess a passable fund of general information. They talk to the examiners readily and plausibly, and tend to make a good impression. Yet it is precisely such cases that present the greatest menace to the service."[16]

With an understanding of the "aim" and the "problem" and "having decided what levels of intelligence are useless" for the Navy, it becomes necessary to select the tests for and adjust the methods of determining admission or rejection.

The most satisfactory manner of meeting the requirements would be to have a psychiatric examiner at each recruiting station, but this is rather too ideal to be practicable. *Per contra*, it is impossible with reliability to reduce the procedure to so simple and expeditious a one as represented by the "group" method. The individual method of giving the preliminary tests as well as conducting the more intensive examination is considered the most satisfactory, and this in spite of great numbers has, by perfecting organization, been found to be possible at receiving and training stations.

The working unit of this organization consists of a yeoman, four psychologic testers, and a neurologist, which, while giving each recruit a personal examination lasting some fifteen minutes, makes it possible to complete an examination every three minutes, and this unit can be multiplied by a figure arising from the rate of recruit inflow.* Figure 40 presents in diagrammatic form a system of psychiatric examinations which has been successfully applied. The psychopath and intellectual defective is discharged from the service, the merely illiterate is held for special schooling, the average normal passes on to general training, and the exceptional, while also given the general training, becomes a candidate for higher training in some one of the several schools for special

* The neurologist can examine an unlimited number of men and need not be included in the multiplication of units.

branches of the Navy. The eligibility of those forming this latter class is arrived at by particular tests.

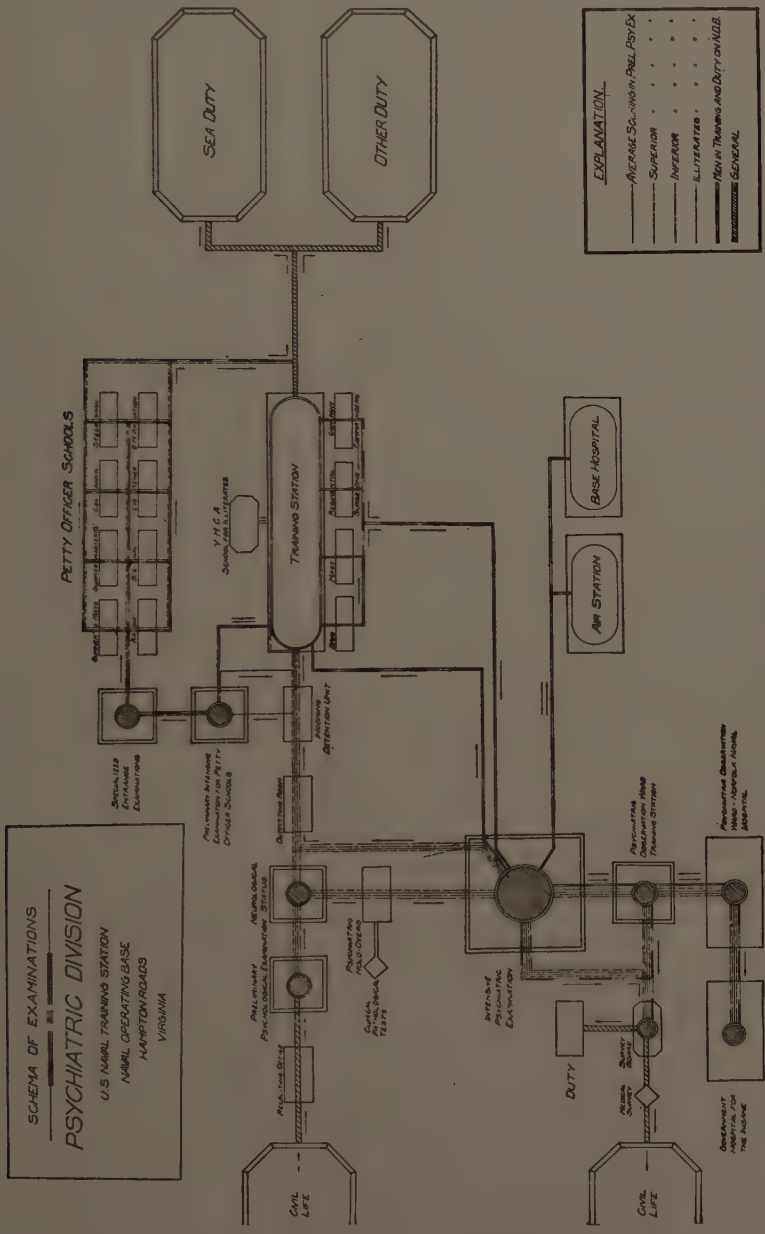


FIG. 40.—CHART SHOWING SCHEME OF EXAMINATIONS BY PSYCHIATRIC DIVISIONS. (From U. S. Naval Medical Bulletin.)

A small but important number of mentally abnormal, undiscovered for one reason or another until passed on to training or out into general service, is sooner or later brought to light and disposed of as a result of

peculiar behavior characteristics observed by officers or companions or of repeated infractions of rules which brings the offender before his Commanding Officer for judgment and disciplinary action. At Training Stations a psychiatrist attends these hearings, and thus the unruly are automatically brought under his immediate observation for determination and an expression of opinion as to the sense of responsibility in a given case. By the means outlined above it is sought to reduce and hold the presence of the abnormal in the Navy to a negligible minimum.

(*b*) **Training Stations and Camps, "Receiving Ships,"* Yards, Ammunition Plants, and Bases, etc.**—It is at such elements of the physical distribution of naval concerns as these that dispensaries are found theoretically to represent the center of medical department activity within them. At any rate, they constitute the accommodations for the direct physical care of the personnel, and these are of primary importance from the point of view of this chapter. The size of the organization varies with the number of personnel and the nature and hazard of the work going on and sometimes with the physical characteristics of the site, if such as to require unusual sanitary supervision. The unit of organization consists of 2 medical officers (the senior in charge), 1 dental officer, 1 Chief Pharmacist's Mate, and from 4 to 8 junior hospital corpsmen (male nurses) of different ratings. This unit, designed to conduct the affairs of one dispensary and its outlying responsibilities (usually there is but one at Yards, Ammunition Plants, and Bases), may be doubled or trebled, depending upon circumstances, as in many cases it was during the late war. At Training Stations, Camps, and "Receiving Ships" the number of dispensaries usually conforms and in our modern institutions does conform to the military organization, each group of regimental habitations or barracks having its own. At the Great Lakes Training Station, for example, in conformity with this system, there are 21. With the multiplication of dispensaries, which means increased size of command and territory, the necessity for central administrative offices develops, the field of medical department interests expands, and the organization becomes more complicated. In witness of this fact the chart showing the organization of the United States Training Station, Naval Operating Base, Hampton Roads, Va., is presented. It illustrates the machinery for the execution of the function or mission of the medical department of training stations which may be briefly stated as follows:

To so study, regulate, and supervise the material provisions, the individual and collective human conduct and the social relations of the Station in point of health requirements as to reduce the morbidity rate to the minimum, and thus further the process of training; to so care for those who may suffer disability because of disease or injury as to give the fairest promise of early recovery, and thus minimize such economic damage as loss of time and mortality; and to carry on intensive medical observation and instruction to the end that men may be transferred to the service

* This term is a relic of the past when ships were always used for receiving purposes. Today it does not necessarily mean a ship, but, whatever the nature of the accommodation, it constitutes a clearing-house for the reception of enlisted men and their distribution or redistribution to general service.

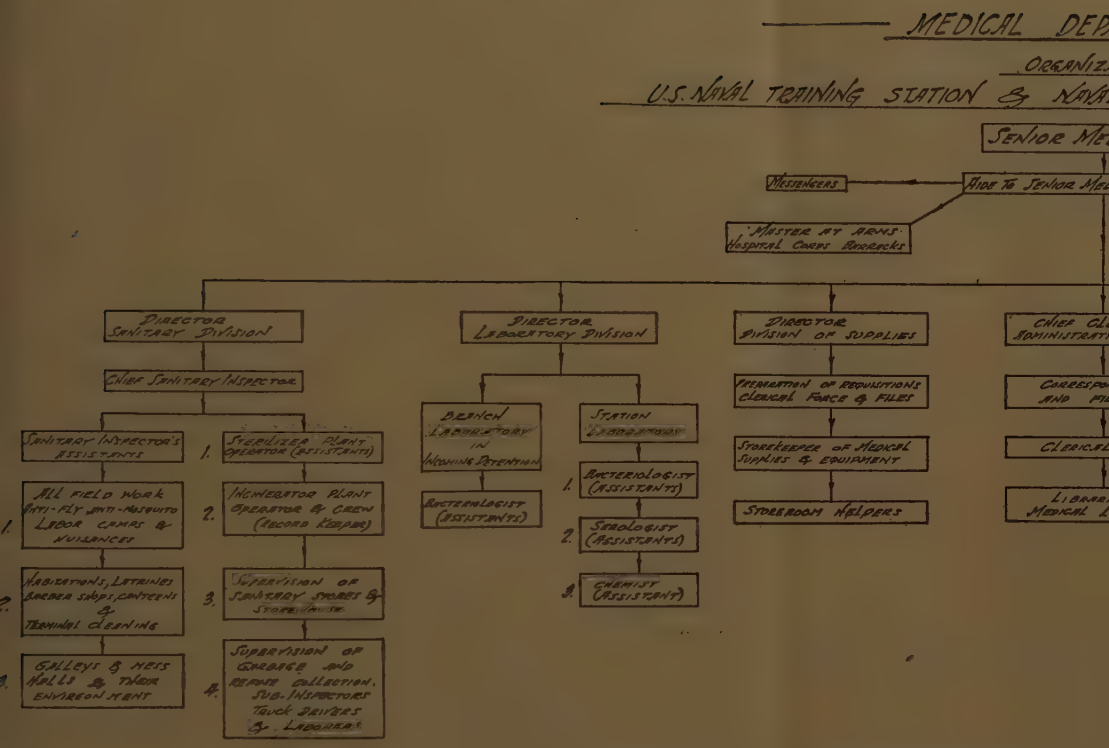


FIG. 41.—MEDICAL O

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NOT TO BE REMOVED

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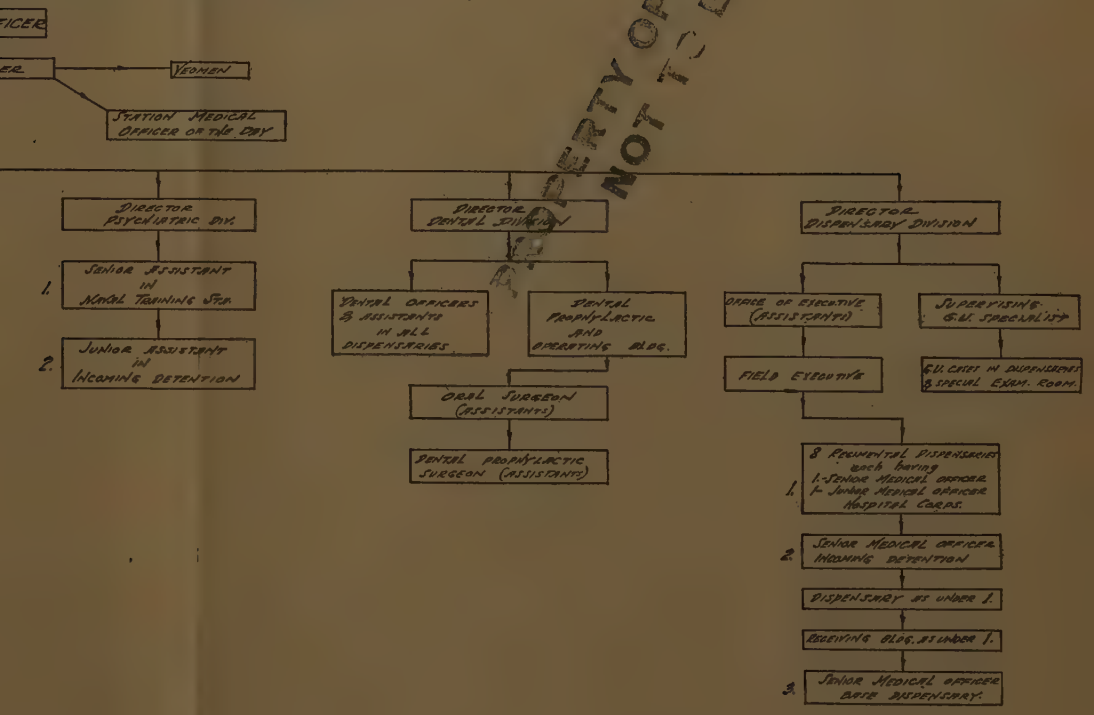
ING BASE HAMPTON ROADS, VA.



OF A TRAINING STATION.

at large both sound of body and mind and free from infection, and with a sufficient knowledge of first aid, personal hygiene, and general sanitation to be individually competent in ordinary accidents and acquainted with those personal and environmental requirements necessary to the maintenance of health.

(*c*) **Training of Medical Department Personnel for Efficient Service.**—So vital is this service division of the organization to the efficiency of the Medical Department that the Surgeon-General naturally and quite properly takes an especially deep and active interest in the facilities for this purpose. They have been enumerated in a previous section of this chapter (p. 177).

The officers of the Medical and Dental Corps come into the Service professionally trained, but they lack much in a special professional as well as in a military sense that the Navy exacts. The primary object of the Naval Medical School therefore "is the training of recently appointed medical officers* in those branches of medical science which are peculiar to naval requirements, or which are of unusual importance because of naval conditions." It is to a certain extent postgraduate in what it gives, but the curriculum covers enough purely professional and medico-naval matter new to the student to give it an undergraduate aspect. Naval hygiene and sanitation or the application of the principles of these sciences under naval conditions, naval law, naval surgery, aërology, epidemiology, and quarantine are subjects new and very special in their meaning to the candidate for active duty in the medical department of the Navy. This is also true of medico-naval features (customs, procedures, and drills), a knowledge of and a deference to which together with a developed spirit of co-operation are large letters in the spelling of success. Certain generally recognized leading branches, such as operative surgery, tropical medicine, and medical zoölogy must be intensively reviewed with emphasis upon practical work to develop abilities of outstanding usefulness. And certain previously studied subjects commonly regarded as specialties, such as ophthalmology, psychiatry, radiology, electrotherapeutics, chemistry, pathology, bacteriology, and other laboratory work, must be retaught in the light of the fact that the frequent professional isolation of a naval medical officer makes it necessary for him to be widely competent in the care of personnel and in the solution of problems coming within his field of responsibility. It is the function of this school, in addition to preparing young officers for their peculiar duties, to give short professionally refreshing courses in these several subjects to older officers of the service as they can be spared from active duty. Its equipment and the organization of the faculty composed of medical officers of the regular Navy under its commanding officer are admirably adapted to the work prescribed.

* The first four dental officers appointed to the service went to the Naval Medical School for training in 1913. During the late war dental officers received the required training for the Navy at the Great Lakes Training Station, assisted by the Northwestern University. Plans for the future in this matter have not been announced, but it is probable, as it is logical, that the use of the Naval Medical School for this purpose will be resumed.

It is unusual except at times of national emergency, for the men who enlist in or are transferred to the Hospital Corps of the Navy to bring with them any experience or training along the lines of their future special duties. In the old days of the Navy, before there was any such thing as a Hospital Corps, the most useless members of the crew of a ship were detailed as "baymen." Now the future attendant of the sick, the future operating room, laboratory and dispensary assistant, the future pharmacist in the Navy is carefully selected for his previous education, character, intelligence, and aptitude, but he must be trained. And he is trained so thoroughly in the different Hospital Corps Training Schools established by the Surgeon-general, and by service experience and tutelage and the guidance of the seniors in his corps and by medical and dental officers that already in the growth of this corps it has a background of fine traditions and has come to be the backbone of medical department service in the Navy.

Before hospital corpsmen take up the particular studies designed to prepare them for the duties of their rate they participate in the general preliminary training for the Navy given to all men. This is an important beginning calculated to provide the perspective necessary to fit a man for Navy life which they would otherwise miss. They are then sent to one or another of the elementary Hospital Corps Training Schools where they pursue a six months' course covering the following subjects[17]: Pharmacy, materia medica, toxicology, chemistry, laboratory technic, hygiene, nursing, dietetics, operating-room technic, preparation of instruments and dressings, anatomy, physiology, first aid, minor surgery, methods of transportation, and stretcher drill. All this is extensive enough to prepare for useful service and lay a substantial foundation for further study, while at the same time giving opportunity to immediate superiors for close observation of the individual and for the determination of inaptitude for the kind of duty involved.[17] The training is now transferred to practical fields of one kind or another in the service—ship, dispensary, hospital, etc.—and there, as their ability merits, they are promoted one grade at a time. Hospital Corpsmen are graduated from the elementary schools as Hospital Apprentices, first class. Between this and that of Pharmacist there are four grades, and from the upper three of these men are sent to the school for Naval Pharmacists and Pharmacist's Mates for advanced training. Here the curriculum is the same as in the elementary schools, with the addition of clerical procedures and forms, bacteriology, therapeutics, preventive medicine and the management of communicable diseases, food inspection, *x*-ray and administration, but all subjects common to both courses are more advanced.

At all times but particularly during war there is a "large and imperious demand for men capable of performing independent duty,"*[18] and it is part of the function of this school to find and train those fit for such responsibility. For this there is a clearing-house which also selects

* By "independent duty" is meant that duty in which the hospital corpsman acts as the sole representative of the Medical Department, either afloat or ashore.

the course to be pursued by each man without reference to the course of any other man. The course is fitted to individuals and the training is individual, designed to strengthen the weak points and round out the capabilities of the one selected.

The term "pharmacist" as applied to the highest grade in the Hospital Corps has a far wider meaning than in civilian life, and although a comprehensive knowledge of pharmacy is necessary to the attainment of the office, *per se*, it plays a very minor part in the duties of those holding the appointment. By reason of their broad acquaintance with Navy requirements incident to long service and varied experience and to their general ability, these officers are particularly useful, and they are called upon to perform numerous special duties, as property and personnel officers, commissary officers, instructors, record and clerical chiefs, and administration assistants, etc. And to help qualify or keep them abreast of progress in the fundamental branches of their profession special courses are at intervals prepared for them by the School for Pharmacists and Pharmacists' Mates. A correspondence course is also carried on for them in the interest of those particularly who are unable to attend the special courses at the school.

In extension of the facilities for instruction above outlined the issue of the three periodic publications previously mentioned contemplates the timely distribution of such information as is deemed of especial value to the several medical department corps in the performance of their duties, and has the ultimate object that the personnel thereof shall continue to advance in proficiency in respect to all of their responsibilities. The *Manual for the Medical Department*; the *Handy Book for the Hospital Corps*; the *Drill Book for the Hospital Corps*; and the *Medical Compend for Masters of the Naval Auxiliary Service* (*Medicine Box, United States Navy*) contain information which is fundamental and directions which guide to efficient service.

(*d*) **Medical Supply Depots.**—These institutions have a direct and important relation to every ship and station of whatever kind or size in the service, their function being to furnish equipment and supplies by order of, or on requisition approved by, the Bureau of Medicine and Surgery, for medical department purposes. The branch supply depots relieve the main depot of the smaller issues in their vicinity, but the stock of these branch depots originates with and is maintained by the main depot. This is the depot at Brooklyn, N. Y., where all specifications for medical supplies for the entire service are prepared and purchases made. Before making award of contract the sample submitted by a bidder is examined, "and each subsequent partial or complete delivery of the successful bidder is examined as to the specified requirements before acceptance."[5] The procedure is not a matter of casual inspection, but an examination as stated, scientifically and exactly conducted, and this, with certain research work in connection with new medical preparations or the question of satisfactory substitutes for unobtainable articles, is the purpose of the laboratories which are a part of the splendid provision for the efficient operation of the supply

feature of the service both as regards adequate quantity and standard quality.

During the war ships bearing these supplies were sunk, but the depot in a wonderful way met all eventualities. At no time was the depot short of supplies; at no time did it fail to send supplies promptly to ships before sailing; and at no time was the quality of the articles issued below standard. This is a creditable record "at a time when the whole world was in the market for such supplies and when the war had depleted the world's stock to a very considerable degree."[18] This is mentioned because the results obtained by an institution always speak effectively for or against its organization and administration

(*e*) **Dispensaries.**—Functionally, dispensaries hold an intermediary position between their own and other branches of the Navy ashore. They represent the out-patient service of the department and are "the court of first appeal" for the sick and injured or wounded of the personnel—both service and civil—of shore stations. Sometimes also, in the absence of other provisions for medical or surgical attention, they are made available to communities adjacent to the Stations. Cases requiring hospital treatment are admitted through them, and some of them, particularly those of Training Stations, are arranged and equipped to carry illness and other disabilities of probable short duration through their course. This is the policy for ordinary times and demands, as regards the extent of professional work to be done by them, and they are organized on that basis. In times of emergency professional services offered by them may be greatly extended and provisions for the unusual are always at hand. Of course, there are many other duties besides the mere care of patients which dispensaries are expected to perform, and these include the physical examination of naval personnel (officers and men) for one purpose or another and of candidates for employment under the civil service. So much for a brief review of their interior function. Their outside interests extend beyond the confines of the particular stations concerned and involve all those matters which should touch the public health sense and arouse the spirit resident in preventive medicine, such as the sanitary condition of the environment, the hygienic conditions and safeguards under which men work, the condition and source of the food-supply and the laws controlling its production, and finally, the nature and scope of the health department and police regulations of neighboring cities for the control of communicable diseases and the suppression in general of those practices and conditions inimical to health.

(*f*) **Hospitals.**—The function of these institutions requires no comment and the distribution and type of the regular naval hospital and of others (Public Health Service and civil) available for naval use have already been mentioned. In this connection, however, it seems desirable to note further that the character of services and capacity offered by each, with other pertinent data, upon the outbreak of war, are made the subject of a communication to the service at large so that commandants and commanding and medical officers may be accurately

informed as to facilities in different localities for the prompt reception of sick or wounded and the procedures in making the dispositions. This information is presented in the form of a convenient table, accompanied by a chart, both showing towns and cities near the coast arranged geographically from north to south, and the governmental and civil hospitals within or near them which are "recommended for the reception and treatment of the sick and wounded of the Navy in time of emergency." It is directed that "in all cases when practicable and no great emergency exists the services of hospitals, dispensaries or quarantine stations of the Navy or United States Public Health Service should be utilized. Should such procedure not be practicable or expedient, the nearest civil institution indicated on the chart having sufficient and proper accommodation should be utilized and reports submitted to the Navy Department, Bureau of Medicine and Surgery." Unless otherwise noted, hospitals shown by both table and chart are general in character.

The division of the country into naval districts and the subdivision of these into section bases determines the administration of hospital service in accordance with them. For hospital purposes all considerable and available hospital facilities (Naval, Public Health, and civil) in or near section-base headquarters are embraced by the district hospital system. At each one of these the treatment of naval inmates is supervised by a naval medical officer and their records are written up by him. Among the several hospitals within each district, one—always the largest naval hospital at the main base—is designated the "Permanent Base Hospital," and it is there that the Director of Hospital Service has his headquarters. Any one of these hospitals may and does accept original admissions, but it is to the latter that the others evacuate, and if other disposition of cases than to duty is to be made, it is accomplished at or by the direction of the permanent base hospital. When demands for the accommodation of patients are in excess of the vacancies at permanent base hospital, they are received at the most convenient Public Health Service or civil hospital. If, however, the cases are of such a nature as to make their immediate admission to the Base Hospital desirable, room is made for them by temporarily transferring convalescent cases to the above-mentioned accessory hospitals or to homes and camps for the convalescent and by sending them on sick leave. The well are, of course, returned to duty, and this in the Navy means that a case is completely cured and able to perform full duty. Other final dispositions are made to hospitals for the insane, to the naval tuberculosis hospital (Los Animas, Col.), or by invaliding from the service.*

The organization of the United States Public Health Service hospitals is peculiar to that Government service; that of each of the civil hospitals is peculiar to itself. This is a matter which does not especially concern the Navy except as to the results in the care of its patients.

* Where reconstruction is required and possible, the cases are handled as described under that heading.

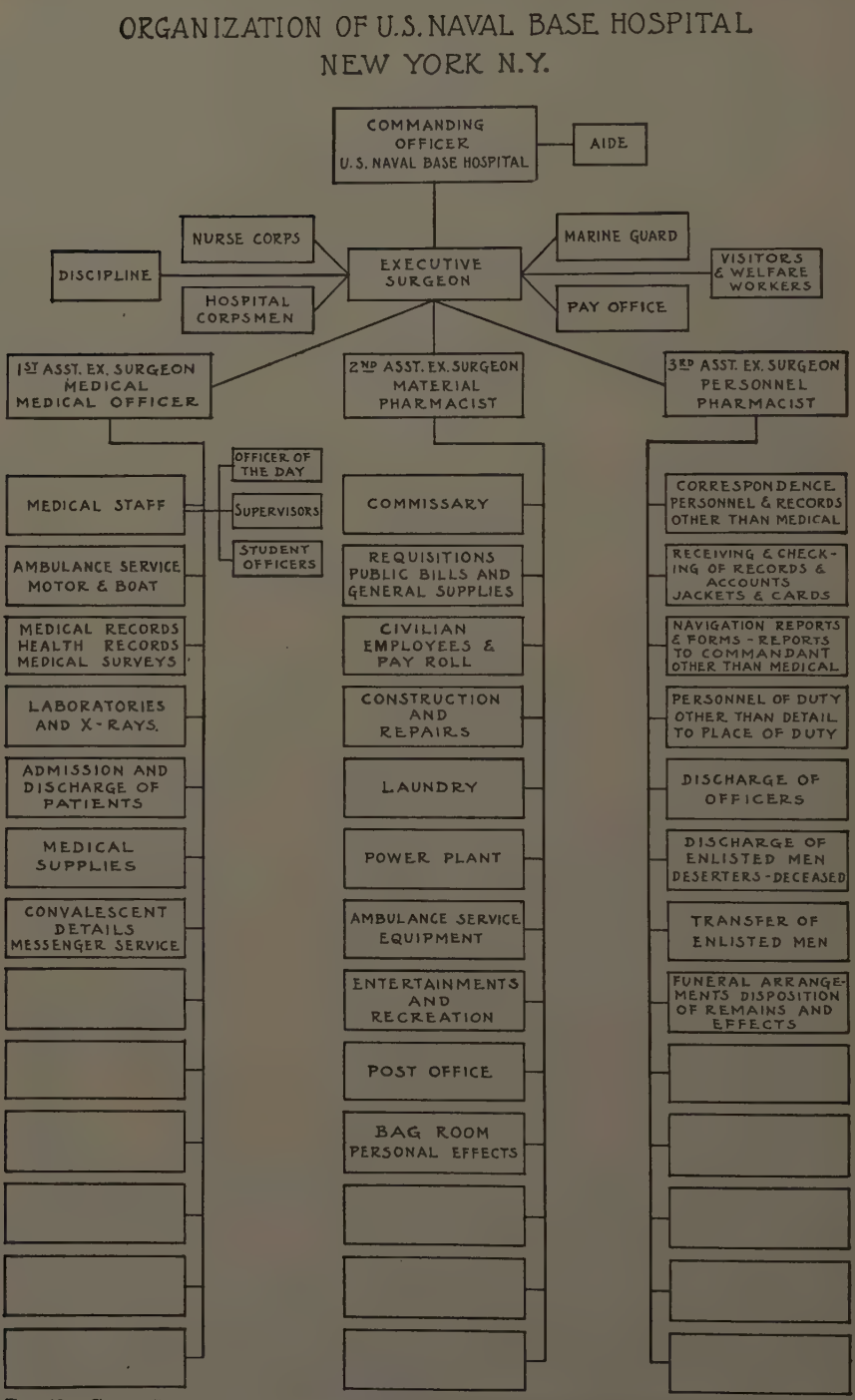

ORGANIZATION OF U.S. NAVAL BASE HOSPITAL
NEW YORK N.Y.
COMMANDING OFFICER U.S. NAVAL BASE HOSPITAL
AIDE
NURSE CORPS
DISCIPLINE
HOSPITAL CORPSMEN
EXECUTIVE SURGEON
MARINE GUARD
VISITORS & WELFARE WORKERS
PAY OFFICE
1ST ASST. EX. SURGEON MEDICAL MEDICAL OFFICER
2ND ASST. EX. SURGEON MATERIAL PHARMACIST
3RD ASST. EX. SURGEON PERSONNEL PHARMACIST
OFFICER OF THE DAY
SUPERVISORS
STUDENT OFFICERS
MEDICAL STAFF
AMBULANCE SERVICE MOTOR & BOAT
MEDICAL RECORDS HEALTH RECORDS MEDICAL SURVEYS
LABORATORIES AND X-RAYS.
ADMISSION AND DISCHARGE OF PATIENTS
MEDICAL SUPPLIES
CONVALESCENT DETAILS MESSENGER SERVICE
COMMISSARY
REQUISITIONS PUBLIC BILLS AND GENERAL SUPPLIES
CIVILIAN EMPLOYEES & PAY ROLL
CONSTRUCTION AND REPAIRS
LAUNDRY
POWER PLANT
AMBULANCE SERVICE EQUIPMENT
ENTERTAINMENTS AND RECREATION
POST OFFICE
BAG ROOM PERSONAL EFFECTS
CORRESPONDENCE PERSONNEL & RECORDS OTHER THAN MEDICAL
RECEIVING & CHECKING OF RECORDS & ACCOUNTS JACKETS & CARDS
NAVIGATION REPORTS & FORMS - REPORTS TO COMMANDANT OTHER THAN MEDICAL
PERSONNEL OF DUTY OTHER THAN DETAIL TO PLACE OF DUTY
DISCHARGE OF OFFICERS
DISCHARGE OF ENLISTED MEN DESERTERS - DECEASED
TRANSFER OF ENLISTED MEN
FUNERAL ARRANGEMENTS DISPOSITION OF REMAINS AND EFFECTS

FIG. 42.—CHART SHOWING NAVAL HOSPITAL ORGANIZATION. (From U. S. Naval Medical Bulletin.)

The organization of naval hospitals, as implied in the section discussing Organization and Administration in general, differs in minor details with each, but, in the main, it is the same throughout the service. This organization is better illustrated than described, and the reader is therefore referred to Fig. 42.

(*g*) **Naval Districts.**—United States naval interests are divided into sixteen geographic districts embracing the territory within the continental limits of the nation and its outlying possessions, with headquarters at the following places, which roughly indicate the relative positions of the districts: District 1, Boston, Mass.; Dist. 2, Newport, R. I.; Dist. 3, New York, N. Y.; Dist. 4, Philadelphia, Pa.; Dist. 5, Norfolk, Va.; Dist. 6, Charleston, S. C.; Dist. 7, Key West, Fla.; Dist. 8, New Orleans, La.; Districts 9, 10, 11, Chicago, Ill.; Dist. 12, San Francisco, Cal., Dist. 13, Seattle, Wash.; Dist. 14, Honolulu, H. I.; Dist. 15, Canal Zone; Dist. 16, Manila, P. I.

The senior line officer of Naval Districts is in command, and is known as the District Commandant, and he is responsible for all general policies and the organization of the district, administering through a staff of aides who are usually the senior officers in their respective corps.

For administrative purposes, naval districts are subdivided into Section Bases, which are regions of activity distant from district headquarters and are self-sustaining in minor matters. Headquarters of these subdivisions if on the coast are usually located at seaports in order to act as bases for the coast patrol. Fleet Bases are entirely distinct from District Bases.

The *Medical Aide*, a member of the Commandant's staff, advises and acts for the Commandant in questions pertaining to all medical department organization and activities, except hospitals, which come under a separate officer known as "Director of Hospital Service," who also comes directly under the Commandant, and between these two there is maintained reciprocal co-operation and close relationship, with mutual exchanges of information. Figure 43 shows the distinct fields of responsibility assigned to each with respect to caring for the sick and wounded.

The Medical Aide is charged with the supervision of general medical and sanitary activities throughout the district, except as above stated; with the establishment, organization, and equipment of dispensaries, temporary hospitals at Section Bases, storehouses and ambulance services ashore and afloat wherever medical and surgical attendance is needed; with making provision for dental services; with supplying medical stores to units of the district ashore and afloat; with an advisory capacity from hygienic and sanitary points of view in respect to the plans for new construction or the remodeling of old; with the enrolment of medical and hospital corps personnel from the various medical centers and their detail to active duty; with the nomination of officers and men of the medical department of the district for assignment to duty; with the inspection, from a sanitary point of view, of every physical constituent of the district including reservations and neighboring territory,

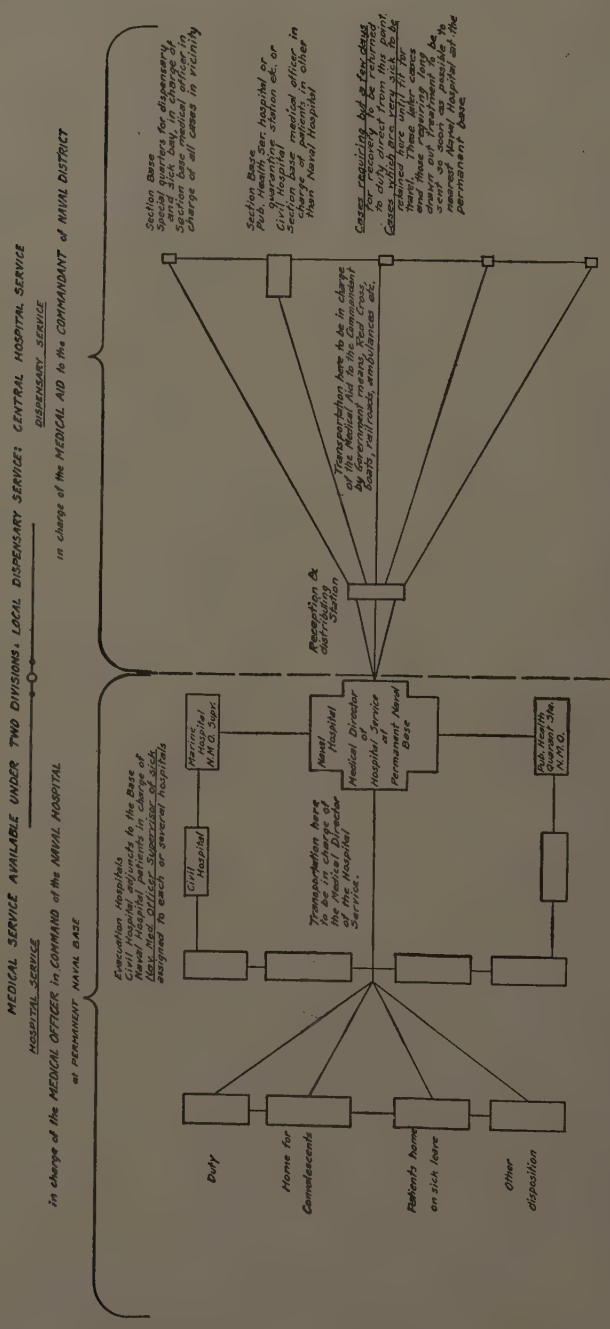

MEDICAL SERVICE AVAILABLE UNDER TWO DIVISIONS: LOCAL DISPENSARY SERVICE; CENTRAL HOSPITAL SERVICE
HOSPITAL SERVICE
DISPENSARY SERVICE
in charge of the MEDICAL OFFICER in COMMAND of the NAVAL HOSPITAL at PERMANENT NAVAL BASE
in charge of the MEDICAL AID to the COMMANDANT of NAVAL DISTRICT
Section Base
Special quarters for dispensary and sick bay, in charge of Section Base medical officer in charge of all cases in vicinity
Section Base
Pub. Health Ser. hospital or quarantine station etc. or Civil hospital medical officer in Section Base medical officer in charge of patients in other than Naval Hospital
Cases requiring bed treatment for recovery to be returned to duty direct from this point
Cases requiring bed treatment for recovery to be returned to duty direct from this point
Case should be sent to Hospital Ship if one is available for transfer. These later cases and those requiring long treatment should be sent as soon as possible to nearest Naval Hospital at the permanent base
Transportation here to be in charge of the Medical Aid to the Commandant and Medical Officers in charge of Boats, railroads, ambulances etc.
Reception & distributing Station
Evacuation Hospitals
Civil Hospital adjuncts to the Base
Naval Hospital, patients in charge of Medical Officer in charge of Base
Naval Medical Officers and Hospital Corps personnel of ships assigned to each or several hospitals
Marine Hospital M.H.O. Supv.
Civil Hospital
Transportation here to be in charge of the Medical Director of Hospital Service.
Naval Hospital
Medical Director Hospital Service at Permanent Naval Base
Pub. Health Quarant. Ins. M.H.O.
Duty
Home for Convalescents
Patients home on sick leave
Other disposition

FIG. 43.—CHART SHOWING ORGANIZATION OF MEDICAL SERVICE AVAILABLE UNDER TWO DIVISIONS—THE MEDICAL AIDE AND DIRECTOR OF HOSPITAL SERVICE OF DISTRICT.

hospitals and district vessels, and, finally, with the transportation of patients from all Section Bases and other outlying points to hospitals, as well as the collection of the sick and wounded and dead from trans-

ports and other vessels in and arriving at ports of the district and their delivery to the Base Hospital. All the material provisions for executing his duties and carrying on medical department work of the district come under his charge, and he is expected to provide and to organize the district medically to meet all possible or probable contingencies.

The *Director of Hospital Service*, as the title indicates, is charged with the control and supervision of all naval hospitals and of others as far as the care of naval patients is concerned within the district of his jurisdiction. It is his prerogative to designate which of the institutions in the system under his command is most suitable for the reception of large numbers and certain types of cases,* and he is responsible for the

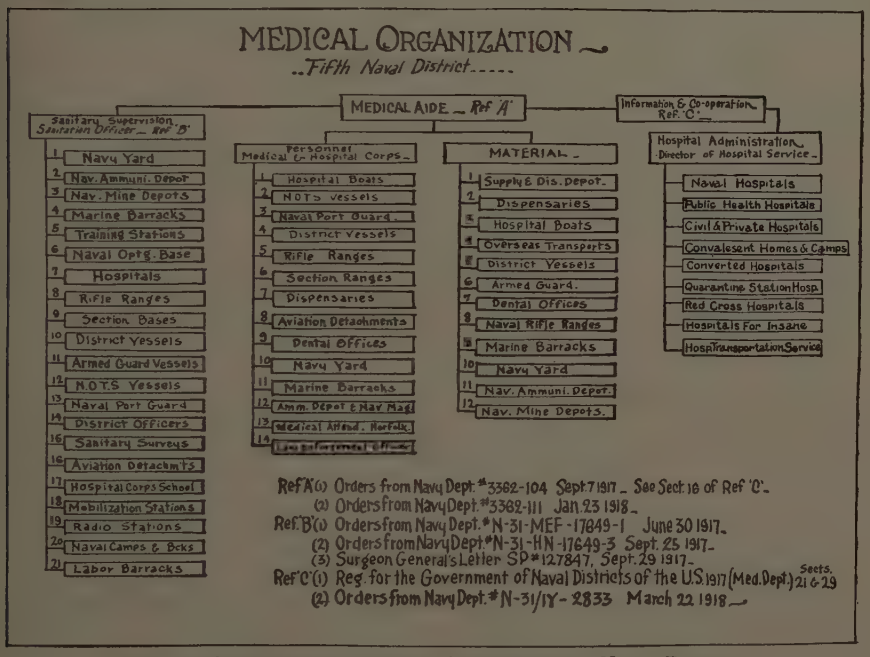

MEDICAL ORGANIZATION
..Fifth Naval District.....
MEDICAL AIDE — Ref 'A'
Information & Co-operation Ref. 'C'
Sanitary Supervision Sanitarian Officer — Ref 'B'
Personnel Medical & Hospital Corps
MATERIAL
Hospital Administration Director of Hospital Service
1 Navy Yard
2 Nav. Ammuni. Depot
3 Nav. Mine Depots
4 Marine Barracks
5 Training Stations
6 Naval Optg. Base
7 Hospitals
8 Rifle Ranges
9 Section Bases
10 District Vessels
11 Armed Guard Vessels
12 N.O.T.S Vessels
13 Naval Port Guard
14 District Officers
15 Sanitary Surveys
16 Aviation Detachments
17 Hospital Corps School
18 Mobilization Stations
19 Radio Stations
20 Naval Camps & Bcks
21 Labor Barracks
1 Hospital Boats
2 N.O.T.S vessels
3 Naval Port Guard.
4 District Vessels
5 Rifle Ranges
6 Section Ranges
7 Dispensaries
8 Aviation Detachments
9 Dental Offices
10 Navy Yard
11 Marine Barracks
12 Amm. Depot & Nav Mag
13 Medical Attend. Norfolk
14 Law enforcement officers
1 Supply & Dis. Depot.
2 Dispensaries
3 Hospital Boats
4 Overseas Transports
5 District Vessels
6 Armed Guard.
7 Dental Offices
8 Naval Rifle Ranges
9 Marine Barracks
10 Navy Yard
11 Nav. Ammuni. Depot.
12 Nav. Mine Depots.
1 Naval Hospitals
2 Public Health Hospitals
3 Civil & Private Hospitals
4 Convalesent Homes & Camps
5 Converted Hospitals
6 Quarantine Station Hosp
7 Red Cross Hospitals
8 Hospitals For Insane
9 Hosp Transportation Service
Ref 'A' (1) Orders from Navy Dept. #3382-104 Sept 7 1917 — See Sect 18 of Ref 'C'.
(2) Orders from Navy Dept. #3382-111 Jan. 23 1918.
Ref 'B' (1) Orders from Navy Dept. #N-31-MEF-17849-1 June 30 1917.
(2) Orders from Navy Dept. #N-31-HN-17649-3 Sept. 25 1917.
(3) Surgeon General's Letter SP #127847, Sept. 29 1917.
Ref 'C' (1) Reg. for the Government of Naval Districts of the U.S. 1917 (Med. Dept.) 21 & 29 Sects.
(2) Orders from Navy Dept. # N-31/1Y-2833 March 22 1918.

FIG. 44.—CHART SHOWING MEDICAL ORGANIZATION OF NAVAL DISTRICT.

distribution and disposition of all patients subsequent to their delivery at hospitals.

(*h*) **Marine Corps.**—This military institution is an important branch of the Navy, and in no way does it show this relationship more objectively than in the fact that the physical link between the one and the other is the Medical Department of the Navy. The Marine Corps is regularly represented by a unit of its organization in the complement of every large ship and performs the soldier's duty at all shore stations. At these posts it shares the services of the Medical Department with the rest of the Navy. But it also performs important detached duty, expeditionary and otherwise; ashore in various parts of the world and

* From this point of view he rarely interests himself in the isolated case or in small numbers.

at such times and places its own medical contingent and outfit is furnished by the Medical Department of the Navy. It is corps "organized" in every other respect, but drawing on the Medical Department of the Navy for its medical and dental officers and hospital corpsmen and for medical equipment and supplies. Members of the Marine Corps are cared for in naval hospitals the same as men of the regular Navy. When serving with marines on expeditions or campaigns and in localities likely to develop the need for either, the Marine uniform is prescribed for officers and men of the Medical Department, and its organization is patterned after that of the Medical Department of the Army for land operation. Special equipment, including that for regimental and brigade hospital units, is provided by the Medical Department of the Navy for this distinctive service with marines, and the instruction of officers and hospital corpsmen at the several schools above mentioned covers all aspects of such service.

(*i*) **Naval War College.**—It has become a custom to detail medical officers to attend and participate in the courses at the Naval War College. This is with a view not only to giving them individually an understanding of the problems of branches of the Navy other than their own and a broader grasp of the relationship of the Medical Department to the operations of the Navy as a whole, but to the presentation of medical department problems and concerns as they bear upon and involve the rest of the service for the information and practical guidance of members of other departments.

"The opportunity thus afforded for a free exchange of opinion, from different points of view, and a better understanding of the aims and efforts of the different branches of the service toward a common goal, goes far toward the training and co-operation which are so essential to service efficiency. . . .

"Specialization is indispensable in a highly complex organization such as the naval service of today, and in the case of medical officers specialization is of necessity carried to an extreme degree. Therein certain dangers arise, for the more active and able an officer may be, the more apt he becomes to center his ideas along restricted lines, losing sight of the ultimate aim of promoting naval efficiency in his enthusiasm for the attainment of more immediate, yet subordinate, results.

"I have repeatedly endeavored to emphasize these views in lectures at the War College and elsewhere, and to impress upon medical officers the necessity of looking upon their duties as primarily military, and not, as in civil life, essentially humanitarian. Anything which brings the medical officer in closer touch with his brother officers in other branches of the service makes for the common good."[20]

B. **Afloat.**—(*a*) **Combatant Ships.**—In addition to the principal types of fighting ship known to everybody, including submarines, torpedo boats, destroyers, cruisers and battleships—each of several classes—there are numerous other small craft of combatant function if not design, such as scouts, mine layers, mine sweepers, submarine chasers, and patrol boats, etc. The personnel of every one of these is provided for medically in a manner varied from a simple medical and surgical chest for use by a layman trained in first aid to the comprehensive organization and equipment of the Medical Department of the superdreadnaught, according to the import of four factors: the size of the crew, the nature and hazard of the duty being performed, the length of the voyage or period of time out of touch with shore stations

or other better medically provisioned ships, and the accessibility or remoteness of outside professional assistance. The circumstances of peace and war influence this question materially, particularly in respect to medical department personnel, as the one reduces and the other increases the first three factors. The peace time policy is to apportion hospital corpsmen at the rate of 1 per cent. of total personnel, and to assign a medical officer when the personnel exceeds 100, with one medical officer for every 500 men and one dental officer for about every 1000 men. All of these allowances are increased in many instances during war, and there are rational exceptions to and variations from them at all times. The policy is merely a standing guide to an approximately accurate estimate of probable requirements in the average case.

With regard to the smaller combatant craft in the second enumeration above, it may be said that the only two types likely to carry a medical officer are scouts and mine layers. The others are cared for in group organizations either by "mother ships," with which they keep in touch and to which a medical officer is attached, or by the Section Base dispensaries where they make port. Many of the smaller of these craft are furnished only with what has been determined to be a sufficient emergency medical and surgical outfit, accompanied by carefully prepared instructions, for use by a layman trained in first aid. When, however, one of them, as sometimes happens, is engaged on protracted distance service an "independent duty" hospital corpsman with additional medical supplies is detailed to it. Some craft with a complement of 30 or more up to 100 and also cargo ships always carry an independent duty hospital corpsman, who, aside from his thorough training and determined competence for such responsibility, enters upon his duties with carefully prepared instructions which are revised and supplemented from time to time as new difficulties are experienced and reported. During the war the cargo fleet increased to enormous proportions and the medical affairs on over 85 per cent. of the carriers were handled by hospital corpsmen[21] not only successfully but in a highly creditable way.*

The independent duty men who serve on cargo carriers are a part of the medical organization of the Naval Overseas Transportation Service (N. O. T. S.) established to expedite the provisioning of military forces beyond continental limits.

The fact that the ships of this service sail under convoy makes it absolutely imperative to act promptly in their preparation to "make convoy" on the date set. The N. O. T. S. medical personnel to meet the requirements within short periods of time after arrivals in ports and before departures consists of an experienced regular medical officer and a staff of assistants varying with the number of ships to be handled at the port in question. They are organized for sanitary inspection, fumigation, supply, medical attention, and the instruction of the ships' companies in first aid and hygiene.

* These men proved to be dependable and equal in every way to the work expected of them.

The subject of *submarines* was briefly considered under the heading Submarine Craft in Vol. VI, but the demands for the successful operation of this particular type of weapon are so foreign to the physiologic requirements of its operators that the internal products of its operation in their effect upon man seem to afford an endless feature for study in the interest of betterment. The principal difficulties are with the mechanics of ventilation and the production of gases. As regards the latter of these there are a number of sources of disabling air vitiation to be controlled. (See page 754, Vol. VI.) Some progress has been made in this direction, but there are also a host of petty discomforts bearing on the question of physical and mental stability, incident to submarine environment, all of which are difficult to solve and some of which seem impossible of solution—dampness, lack of adequate heating and bathing facilities, limitations of fresh food storage, continuous poor artificial illumination, confinement in cramped quarters, lack of exercise, monotony, variations in atmospheric pressure (submerged and on the surface), and the disquieting effect on morale of conditions of prolonged submergence, particularly in the presence of an enemy.* Indeed, all of these defects become seriously exaggerated in war.

Without going into details as to the *modus operandi* of these several influences, it is apparent that the standards of physical requirement† in determining fitness for this service must be rigidly observed; and that there are certain special diseases‡ and accidents (injuries)§ peculiar to submarines.

* Lieutenant Commander E. W. Brown (M. C.), United States Navy, an unpublished paper on the Medical Aspect of the Submarine Service.

† "While no set standards have been laid down as in the aviation service, it is important to exercise great care in the examination of candidates for submarine duty. There are characteristic hazards and disabilities to be considered. Strong eyes are essential on account of the long periods of periscopic use and the fact that practically all work in submarines is done under artificial light which is inherently unsatisfactory in submarines. Sound cars are important in view of the large proportion of ear disabilities which develop. Submarine duty involves particular risk to ears in which there have been any previous defects. It is not a question of accidental injuries, but rather continued exposure to certain damaging conditions so that sooner or later the disability becomes evident. The situation is in close analogy to that of telephone workers. Observation made with this class of workers at intervals in cases with normal or approximately normal hearing have shown very little change even in years of service, while in persons with appreciable defects of hearing on entering the service, a further loss is noticeable after prolonged occupation in telephone work. Variations in atomspheric pressure are important in this relation, as continued exposure to increased pressure with the subsequent return to normal pressure, if too rapidly made, results in circulatory changes in the middle ear impairing the hearing. In the earlier stages of impairment of hearing, as the result of exposure to loud and continuous noise, such as the operation of Diesel engines, clinical observation shows depression of the membrana tympani consequent upon retraction of the tensor tympani muscle—this objective evidence appearing in advance of the thickening process in the middle ear."

‡ Diesel engine deafness and eyestrain have already been discussed at length. A rash designated as *fuel-oil rash* has been reported at various times in the British Submarine Service. The lesions are suggestive of scabies, are very resistant to treatment, and are induced by some constituent or constituents of certain types of fuel oil.

"*Intestinal stasis* is characteristically prevalent in submarines. This is the result of confinement in a cramped space with enforced physical inactivity and the

use of an overconcentrated diet. This has proved to be an obstinate feature of submarine routine.

"*Electric welding:* Submarine tenders are equipped with electric welding plants. In this process the light produced is very intensive (equal to almost 8000 candlepower), and as the operation has to be closely observed, the workmen must protect their eyesight by shields composed of alternate layers of colored glass. The light and heat evolved are sufficiently intense to cause a condition of the skin comparable to sunburn. This electric light is redundant with ultraviolet rays which may produce lesions of the conjunctiva, cornea, and retina, the symptom-complex being conveniently designated as *electric ophthalmia*. A considerable number of cases have been reported. The screen employed is a combination of medium green and red. Its proper use is of the utmost importance.

"*Nose and throat affections:* These are encountered among submarine men with great frequency, the submarine environment apparently favoring the occurrence of catarrhal conditions of the nose and throat, although it is probable in most instances an aggravation of a pre-existing condition. Undue dryness of the air of interiors is said to aggravate existing nose and throat affections. The situation in submarines cannot be accounted for by low relative humidities, as, on the contrary, the relative moisture tends to be high, particularly when submerged. In fact, it tends to be much higher than in large ships or in homes, schools, and office buildings. Temperature conditions, however, may be a factor—the temperature of a submarine in the winter season is unduly low, as a rule, owing to difficulties in heating. Under such circumstances catarrhal conditions would tend to get worse, coldness of the hands and feet tending to cause congestion of the nasal mucous membrane.

"There are, however, other conditions in submarines which are capable of having an untoward effect upon the mucous membrane of the nose and throat. There is, as a rule, a varying amount of oil fog originating largely from the relief valves of the engine in the engine-room. At times this is very dense, extending to adjoining compartments and inducing an annoying irritation of the nose and throat. The fumes of cooking—frying in particular, containing acrolein and related volatile bodies—produce irritation of the eyes, nose, and throat. Another contributory factor is the irritation from the batteries due to sulphuric acid spray—this is more marked in a heavy sea with marked rolling submerged—the acid being evolved and carried off mechanically with the evolution of hydrogen from the cells during discharge. This material produces at times sufficient irritation to give rise to coughing and sneezing.

"The submarine is not a habitable vessel for a prolonged period without physical deterioration. This has even been noted in the case of officers and men under peace conditions, but under war routine, when patrol periods may average eight to ten days at sea, this tendency was especially marked. The lack of physical exercise, the unfavorable air conditions, the artificial light, the monotony and crowded condition all tend to a lowering of resistance or even exhaustion. Exhaustion is insidious and may not be demonstrated until the individual is overcome by one or the other of its symptoms. Relaxation and change are of the greatest importance to the submarine personnel and with it keenness and the prevention of the condition known as staleness."

§ "The submarine is liable to certain characteristic accidents which may be grouped as follows:

"(*a*) *Battery explosions:* Toward the end of charging large quantities of hydrogen are given off from the cells, and it is imperative that the ventilation be adequate to insure sufficient dilution below the explosion point which varies from 8 to 10 per cent. If such an explosion mixture is formed there will be a serious risk involved in view of the danger of electric flashes from short-circuiting and possible touching off of the mixture below decks. A number of such explosions have occurred. The importance of reliable tests for the efficient supply of air to the storage batteries and the determination of the percentage of hydrogen present is obvious.

"(*b*) *Chlorin poisoning:* Chlorin will be evolved if salt water has access to storage batteries under discharge conditions. The high toxicity of chlorin and its physiologic effects are too well known to merit any special mention here. Flooding of the battery cells has occurred in the following manner: While on the surface, air is drawn over the cells to prevent an accumulation of an overdue percentage of hydrogen, and is discharged by a blower through a ventilator alongside of the conning tower. During surface cruising in heavy seas salt water has gained access to the battery. Prior to diving this ventilator is unshipped and the valve secured. Failure to close this valve on submerging has occurred and the battery has been flooded

Submarines are organized into divisions composed of a variable number "usually of the same class . . . and based on a mobile tender or mother ship."

"The Medical Officers of a division which may consist of as many as ten boats are quartered aboard the tender or mother ship. The medical department is made up of a sick bay space proper, a dispensary, an operating room, an isolation ward, and necessary storerooms. It is not customary to detail a medical officer or hospital corpsman to submarines even on protracted cruising. A submarine is, however, equipped with a first-aid outfit made up of suitable medicines and dressings, and the crew instructed in first aid. Special emphasis in first-aid instruction is laid on such matters as eye burns from the sulphuric acid of storage batteries, electric shock, chlorin poisoning from storage batteries, technic of air purification, use of chlorin gas, masks, etc.

"It will be obvious from the foregoing that the Submarine Medical Officer is a distinct specialist in one phase of naval activity. He must have special knowledge of ventilation and gases in their relations to submarines; of the technic of air purification and the effects of increased CO_2 and decreased oxygen from the physiologic standpoint; of such gases as chlorin and arsenic; of the physiologic effects of air pressure; of the functional tests for vision and hearing and treatment of such defects; of the physics and physiology of diving; and special knowledge of the proper conditioning of men for this very exacting and arduous form of naval service. He is, in addition, frequently called into consultation in matters connected with examination of water for battery purposes, of battery electrolyte analysis for curtailments, and the testing of fuel and lubricating oils for sea-water contamination."

What has been said of medical personnel and provisions on board cargo carriers under N. O. T. S. direction is in general true of destroyers. "For years it has been found that as a rule, a destroyer can operate successfully without a commissioned medical officer (doctor) on board."[22] The number of medical officers which would be required in order to put one on each destroyer is never available, but even if it were possible in point of mere numbers, it is not necessary and would be an indefensible waste of ability. For each such vessel, therefore, the policy is to furnish an independent duty hospital corpsman—usually a Chief Pharmacist's Mate. The equipment is complete and liberal for the services expected of him, which, although he is not in any sense considered a substitute for a well-qualified doctor, are the care of all manner of emergencies in the way of illness or injury. Ordinarily his duties are:

(*a*) To care for the ordinary ailments and injuries of the crew while at sea;

(*b*) To administer first aid to any serious case that may occur;

(*c*) To maintain his supplies in proper amount and condition to meet ordinary contingencies; and,

(*d*) To make out for forwarding the necessary medical forms and keep the necessary medical records.

with sea water. Until the battery was shut off chlorin was rapidly evolved and a number of cases of chlorin poisoning resulted. Such a situation would involve grave possibilities if the submarine could not be immediately brought to the surface.

"(*c*) *Arseniuretted hydrogen* (AsH_3): Poisoning by this gas in serious epidemic form occurred in British, French, and Italian submarines during the late war. Almost an entire personnel was affected in certain instances. This occurred as a result of the "action of nascent hydrogen on the grid material of the battery plates. The chronic anemia resulting in some cases produced permanent disability. The replacement of contaminated battery plates and acid prevented further difficulties from this source."

It is his duty also to inform the commanding officer of any suspected contagious or infectious disease that may appear on board or when a patient is otherwise in need of the services of a doctor and to make provisions for the indicated accommodations; to calmly and quickly and efficiently aid the commanding officer in the maintenance of the morale of the crew in the presence of disease or injury on board; and, in the event of death, properly to care for the body.*[22]

Like submarines, *destroyers* are organized into groups and ordinarily depend upon the "mother ship," where the division medical officers are quartered, for all medical needs beyond the ability of the hospital corpsmen. When the boats are in touch with the "mother ship" inspections are made and close general supervision is exercised by the Medical Officers over all matters of medical department concern.

Of course, when a destroyer is engaged on distinctly independent duty of a hazardous nature with the probability of prolonged separation from the group, a medical officer as well as a hospital corpsman is assigned to the ship. The exigencies of war and the conditions under which destroyers frequently operate at such times create the very necessity of which I speak, and those engaged in the "war zone" during the late war hunting and protecting against submarines included medical officers among their personnel.[23] There was a great deal of work to be done by them, not the least of which was the care of rescued victims of submarine activity.

From the point of view of medical department organization and service cruisers and battleships may be discussed together, for what is said of the latter applies to the other. Consideration of the battleship as a type will be taken up at more length when I come to modify and supplement the information contained in Vols. IV and VI. It need only be said further in connection with organization for service with the forces afloat that in accordance with the military dispositions of the components of the fleet the general conduct of the medical department on each of a group of ships comes under the supervision of a Division Surgeon or Force Surgeon, representing the Division or Force Commander concerned, and that these, in turn, come under the supervision of a Fleet Surgeon, representing the Commander-in-Chief.

(b) **Ships Composing "the Train" of the Fleet.**—Ships composing "the Train" of the Fleet from the point of view pertinent to this chapter can be dismissed with very brief comment. They consist of supply ships, repair ships, colliers, ammunition ships, mail and dispatch boats, etc., and each is provided with medical personnel in accordance with the policy previously mentioned. The complement of each rarely if ever entitles them to more than one medical officer, and two, or at most, three hospital corpsmen, which experience, even in war, has demonstrated to be adequate. The medical accommodations, equipment, and supplies apportioned in conformity with a carefully estimated probability of demand for services corresponds in completeness and up-to-

*Attention is invited to the subject of embalming under Service Division of Organization Afloat, III, 2, B (*d*).

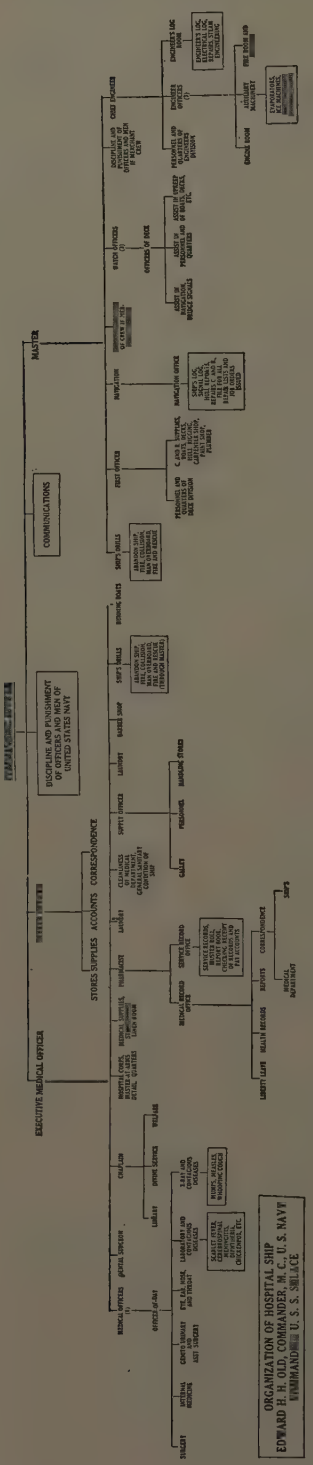


FIG. 45.—CHART SHOWING ORGANIZATION OF A HOSPITAL SHIP. (From U. S. Naval Medical Bulletin.)

date character with those provided for the larger ships of the Navy.

(*c*) **Hospital Ships.**—The Hospital Ship is theoretically a constituent of "the Train," and for administrative purposes it comes under the command of its commander. In times of peace on the high seas and at anchor in port it is often physically present as such, but its neutral character in contrast to the unneutral character of the other elements of "the Train" imposes the necessity of separated and independent movement during war.

It has been said that a hospital ship is assimilated to a hospital. This is unquestionably true from the point of view of function and of professional accommodation, equipment, and general internal operation; but there is a radical difference as regards organization, in that there are two departments, a medical department and a nautical department —each with quite distinct functions, though co-ordinated in ultimate common mission under the Commanding (Medical) Officer. This separateness in organization is very clearly illustrated in the accompanying chart (Fig. 45),[24] but properly administered it is possible to avoid any consciousness of it as a deterrent to harmonious action and the full realization, as stated, of the common mission—the relief of the sick and wounded.

"On a hospital ship the interests and duties of the medical department take precedence, except that the master must be unfettered in the discharge of his duty as relates to the navigation and safety of the ship.

"It may be stated that the non-medical part of the organization occupies on the hospital ship a position analogous to that of the medical department on a combatant vessel. In each case, while occupying a subordinate position, the navigator or medical officer is left free to carry out his special duties,

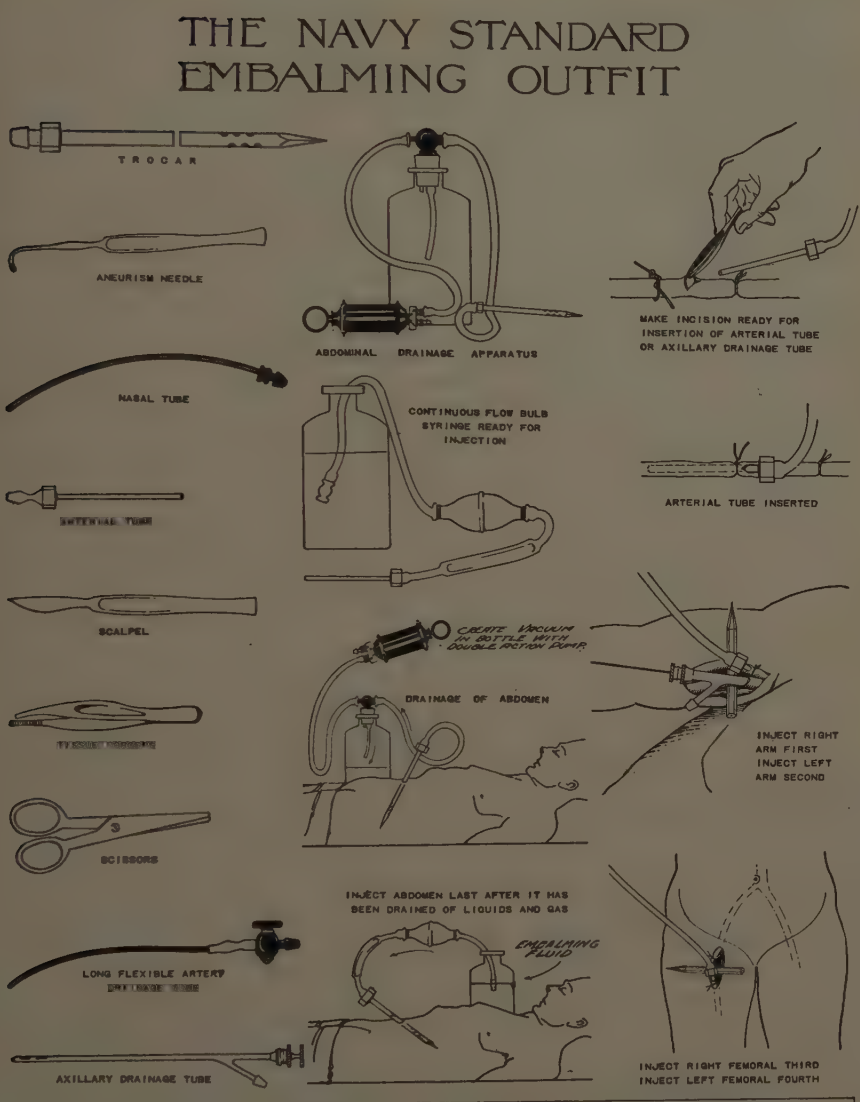

THE NAVY STANDARD EMBALMING OUTFIT
TROCAR
ANEURISM NEEDLE
ABDOMINAL DRAINAGE APPARATUS
MAKE INCISION READY FOR INSERTION OF ARTERIAL TUBE OR AXILLARY DRAINAGE TUBE
NASAL TUBE
CONTINUOUS FLOW BULB SYRINGE READY FOR INJECTION
ARTERIAL TUBE INSERTED
SCALPEL
CREATE VACUUM IN BOTTLE WITH DOUBLE ACTION PUMP.
DRAINAGE OF ABDOMEN
INJECT RIGHT ARM FIRST INJECT LEFT ARM SECOND
SCISSORS
INJECT ABDOMEN LAST AFTER IT HAS BEEN DRAINED OF LIQUIDS AND GAS
EMBALMING FLUID
LONG FLEXIBLE ARTERY
AXILLARY DRAINAGE TUBE
INJECT RIGHT FEMORAL THIRD INJECT LEFT FEMORAL FOURTH
① PREPARE EMBALMING FLUID
℞ LIQUID FORMALDEHYDE 15.5 MILS.(C.C.)
BORAX (Sodium Borate) 5.0 GRAMS.
WATER (Sufficient to make) 100.0 MILS (C.C.)
FOR 150 LB. MAN 10 QTS. 10,000 C.C.
FOR 200 LB. MAN 15 QTS. 15,000 C.C.
BE CAREFUL NOT TO OVER INJECT ARTERIES. TWO (2) QTS. MAY BE SUFFICIENT. INJECT UNTIL CLEAR FLUID RUNS OUT OF BASILIC VEIN.
②ASSEMBLE OUTFIT FOR USE.
③INSERT AND TIE AXILLARY DRAINAGE TUBE IN RIGHT BASILIC VEIN AND LEAVE IN UNTIL ALL INJECTIONS HAVE BEEN MADE.
④INSERT AND TIE ARTERIAL TUBE IN RIGHT BRACHIAL ARTERY. INJECT FLUID UPWARD THEN DOWNWARD. NEXT INJECT LEFT BRACHIAL.
⑤INSERT ARTERIAL TUBE IN RIGHT FEMORAL ARTERY AND INJECT DOWNWARD ONLY. THEN INJECT LEFT FEMORAL.
⑥INJECTION OF THE CAROTID ARTERY IS SELDOM NECESSARY.
⑦ABDOMINAL DRAINAGE AND INJECTION OF ABDOMINAL CAVITY.
⑧TIE UP ARTERIES AND VEIN AND SEW UP INCISIONS IN THE SKIN.

FIG. 46.—THE NAVY STANDARD EMBALMING OUTFIT. (From the Supplement, U. S. Naval Medical Bulletin.)

and we have yet to hear of a line officer who would direct the medical officer how to operate or of a medical officer who would seek to in-

struct the navigator as to the measures to take in an emergency affecting the safety of the vessel."[25] The Medical Department comes directly under the executive surgeon and the nautical department under the master.

(*d*) **Embalming.**—Before leaving the subject of general service "afloat" mention must be made of a new order of things as far as the Navy is concerned in what generally is and will continue to be a picturesque ceremony attending life's termination at sea. Until the recent past the families of those dying on board ship more than three days out from the port of destination, even if a home port, rarely had opportunity to testify their grief in the sentimentally cherished and traditional manner. It seemed in the bureau's thoughtfulness, with the increasing naval personnel and the greater likelihood of deaths at sea incident to the war, that something could be done in deference to the popular wish to exercise this last privilege in the funeral rites. The simplicity of the art of embalming seemed to make burials at sea unnecessary, at least in the Navy, and in accordance with this idea steps were immediately taken to equip each ship with a set of the instruments and apparatus required and a varying number of hermetically sealable metallic lined shipping caskets. The subject was included in the curriculum of the Pharmacists' Mates School and written instructions were prepared and issued for the benefit of the medical department personnel already scattered throughout the service afloat, covering the technic of embalming and preparing remains for shipment or burial and the requirements of the law regarding the interstate transportation of remains. All this is in supplement to the medical department's usual care of the Navy's dead and is more than compensated by the gratification it gives the next of kin.

IV. BATTLE CONDITIONS OF THE PRESENT DAY

Before passing on to the clearly military subdivisions of this heading, and with reference to the special conditions arising incident to service afloat, as considered under Battleship Conditions of the Present Day, Vol. VI, p. 751, I wish to reopen the subject of resuscitating the asphyxiated. In discussing the methods of artificial respiration mention was made of a mechanical device as of possible use, and I do not wish to retract from that mild statement, but I do wish to emphasize in that connection that experience verifies the common-sense view of The Third Resuscitation Commission, "That reliance upon the use of special apparatus diminishes greatly the tendency to train persons in the manual methods and discourages the prompt and persevering use of such methods." I entirely agree with the words of Taylor,* who expresses the gist of the appendix to the report of the commissioners, "that the fact that in most accident cases no apparatus is at hand for immediate use is a matter of congratulation rather than regret."

In extension of the question of deep diving briefly mentioned in Vol. VI, it is well here to note in evidence of the legitimacy of its con-

* United States Naval Medical Bulletin, vol. xiii, No. 2, p. 337.

sideration as incident to accidents in service afloat that the Navy's work in raising the submarine U. S. S. F-4 brought about valuable observations and exhaustive studies of the subject by the medical department which are now added to the epoch-making investigations of the English and Italians. French[26],[27] is particularly identified with this work.

"All accounts agree that the battle of Jutland was the most costly in lives and ships of any sea fight in British or German naval history." The more general and increasingly effective employment of torpedoes by first line ships as well as by destroyers and submarines brings the medical department of cruisers and battleships face to face with the necessity to anticipate the highly possible contingency of a rapidly sinking ship, which entails the obligation to organize to abandon ship with the sick and wounded under his care and makes it hazardous to establish dressing stations for purposes of protection too deep in the structure of the ship. The more common use of explosives and gas shells, particularly with the high angle fire of long range heavy guns and bombs from air craft, also suggest the simultaneous disablement of large numbers of men, and these realized sources of danger have led to various structural changes and measures calculated to prevent or minimize the possible destruction.

"The new ships are provided with the best kind of protection against torpedoes and mines and will be equipped with mine-sweeping gear which has proved successful in the war. Particular attention has been paid to the bulkheads and decks to provide adequate subdivision of the vessel so as to maintain water-tight integrity as well as to prevent the spreading of poisonous gases from exploding shells. The ventilation systems also have been laid out with a view to preventing poisonous gases reaching compartments in which men are stationed during battle, and the air supply to the vital stations occupied during action will be purified."

Splinter mats (specially constructed mattresses* are used to protect all the exposed positions on the superstructure at which officers and men are stationed during action—bridge, anti-aircraft gun platforms, searchlight positions, and tops. (See Fig. 47.) Screens of wire rope are used to prevent penetration by fragments in weakly protected areas on gun decks, and suspended from deck beams screens of this or similar description are used to protect secondary battery positions. The necessity of closed hatches† to assist water-tight integrity and prevent the easy entrance of missiles or their fragments to lower decks is fully realized, and its rigid enforcement, of course, complicates access to the wounded and again emphasizes the importance of general first aid and training.

On one of the British ships at the battle of Jutland a shell detonated

* In lieu of these, ordinary mattresses will serve the purpose.

† The British provide small easily and quickly closed manholes in all hatch covers which severely limits the type of stretchers—in our own service to such as the apron stretcher (Lung).

on the gun deck; fragments killed two officers and a number of other persons. The majority of casualties, however, were from the fumes of the detonated T. N. T., which became quite widely distributed. The total casualties from this one hit were 58.

The antigas mask or helmet is a matter which has been marked by rapid evolution, beginning with the early realized necessity for something of the sort in the Navy as a protection against the gases resulting from

FIG. 47.—ARRANGEMENT OF SPLINTER MATS ON SUPERSTRUCTURE OF SURFACE COMBATANT SHIPS TO PROTECT THOSE PERFORMING DUTY IN OTHERWISE EXPOSED POSITIONS.

shell explosion, etc., and finally stimulated by the concentrated use of poison gases by Germany. Measures to protect against the gas fumes of bursting shells and burning cordite have been studied, looking toward their general adoption in the fleet. The efforts made in this direction have had two objects—one, to diminish the gases which may be delivered into compartments through the plenum ventilating system by enabling the occupants to shut off the current to the fan by a switch located in the compartment itself; the other, to provide protective

respirators in sufficient numbers. The Germans are reported to have worn gas masks on all ships and at every post of duty, which inferentially suggests that they fired gas-charged shells.

"By the autumn of 1917 a type of gas mask had been evolved for the Navy embodying certain features of the standard German mask and other features of the standard Army gas mask. In the autumn of 1917 a group of naval medical officers from the fleet were ordered to the Naval Medical School, Washington, D. C., for a course of instruction in gas warfare, and this course was followed by subsequent ones, to which were ordered both medical and line officers. A few months later a board composed of medical and line officers was convened in the Atlantic Fleet to draw up standard rules for training officers and men of the fleet in the principles and practices of gas defense."*

Many cases of burn resulting from the Jutland engagement demonstrated that covered portions of the body are rarely burned by cordite. It is realized that this is not the case if the burning cordite is in sufficient quantity and the victims are in a closed space like a turret, magazine, or handling room, and it is probable also under these circumstances that the protection offered by specially prepared garments would not be adequate to prevent severe injury†; but as many casualties from burns occur about secondary batteries and among ammunition parties in the open deck spaces, such a measure of protection as specially prepared antiflash clothing has been considered worthy of adoption. "The amount of flame developed by a bursting projectile is difficult to estimate, but the immediate incendiary effect is generally small and fires consequent on a shell burst are usually started by heated fragments igniting cordite or other inflammable substances." The prevalence of burns in the naval action of the war quickened interest in the subject, and it was found both at trials and in action that flash-proof clothing (garments of wool are the best) gave good protection to personnel against flash and fire. This idea of rendering fabrics fire resisting has been extended, and it is understood that the sleeve or tube fitted to the delivery opening in magazine doors, through which cordite charges are delivered, is by the British now being treated with fire-resisting chemicals.

The imminence of disaster to entire ships has also brought about larger and more dependable provision for both collective and individual life saving, the former in the form of circular air-chamber rafts, the latter in the form of a jacket preserver stuffed with a new vegetable material known as Kapok. It has a very high buoyancy power and for this reason among others has been used in the manufacture of ship's mattresses, but it is also extremely combustible, and for this reason, in connection with the subject of the preceding paragraph, is decidedly objectionable unless it is found possible to fireproof it without destroying or seriously impairing the virtue it holds out to the seafaring.

* The personal notes of Lieutenant-Commander R. H. Laning, Medical Corps, U. S. N.

† The heat generated by the explosion of powder is in the neighborhood of 4000° C.

1. Provision for the Sick and Injured or Wounded

A. **Accommodation.**—(*a*) The sick quarters have advanced in commodiousness with the increasing size of ships and in arrangement and equipment according to the latest and best professional standards—facts shown better in the accompanying illustration than by many words of description. Nothing that was said under this heading in previous volumes need be retracted. What we have to contemplate today is an improvement all along the line of what years ago seemed and was perfection for its day.

(*b*) **Battle dressing stations,** long sought as entirely feasible in ship design and construction without in the least impairing fighting efficiency, have, in the last six or seven years, been realized in increasing

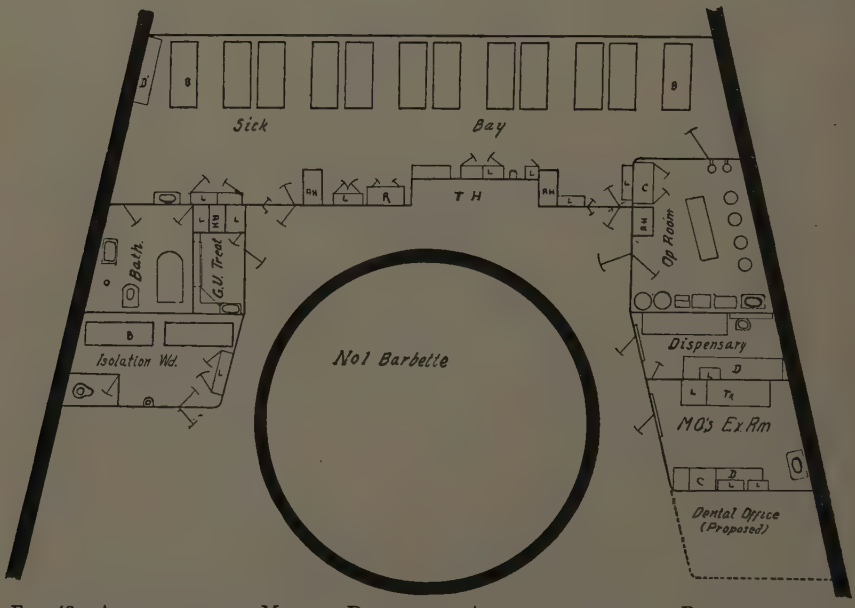


Fig. 48.—Arrangement of Medical Department Accommodations on a Battleship of the Superdreadnaught Class. Note That the Bunks in Sick Bay are Two Tier.

measure, until now on the newer ships of superdreadnaught class provision seems all but if not quite ideal from the degree of protection afforded and space allotted and the professional features. Two of them are provided—one forward and one aft—as shown by the accompanying illustration (Fig. 49). On the *Mississippi* they are located on the berth or third deck of the ship and are doubly protected outboard by armor belt and a row of storerooms. The inboard bulkhead of all of these except the battle station storerooms is alone indicated on the plan. Overhead is a protective deck. In spite of the presence, particularly in the forward station, of blower motors, trunks, and ammunition handling machinery, the spaces are roomy and access to them from the parts of the ship which each serves is reasonably convenient. The fixed equipment for the medical department at each station consists of

the following: Two reserve fresh-water tanks (overhead), each of 128-gallon capacity*; a lavatory for scrub-up purposes; a sink for waste; a sanitary drinking fountain used in battle only; a tap for drawing water off into buckets and basins, etc.; a steam water heater†; an electric water heater in supplement to the other in case steam fails; emplacements including steam and electric connections for sterilizer; emplacements for sterile dressing containers with a special electric connection for the towel heater; four folding broad steel shelves for extra dressings and instruments, and numerous extra electric plugs for additional lights and apparatus. The important electric connections above enumerated are on the battle power circuit to insure the utmost reliability.

Besides a complete assortment of instruments, a set of surgical furniture is available for each station, that for the forward station being the "sick bay" operating-room outfit; that for the after-station being a duplicate set (operating-table, portable sterilizer, sterile dressing container in rack, and chairs) stowed in the after-dressing station store-room. To increase the capacity of the dressing stations for the accommodation of the sick and wounded an ingenious method for tiering stretchers is employed as illustrated in Fig. 50. Some of the

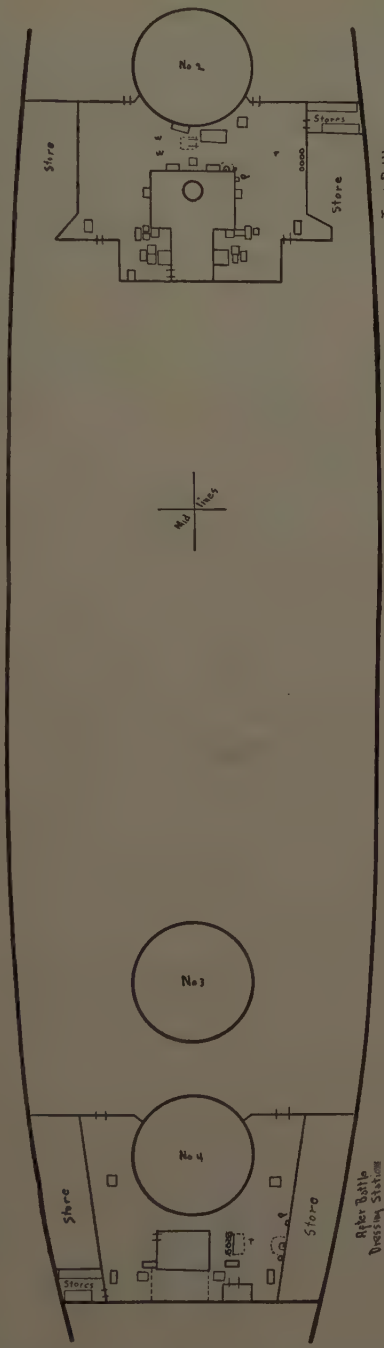


FIG. 49.—CHART SHOWING POSITION AND ARRANGEMENT OF THE BATTLE DRESSING STATIONS ON A SHIP OF THE SUPERDREADNAUGHT CLASS.

* The keys to the fresh water-supply line are at the stations, so that these tanks can be refilled whenever necessary.

† The foregoing fixtures are at ordinary times enclosed within a stout removable wire caging so that they cannot be tampered with.

storing space outboard of the station is assigned for use as mortuaries. The operating table is placed convenient to the surgical fixtures and under a bracket with special connections for high-power electric lamps.

A particularly valuable feature of these dressing stations is the storeroom provided for each, in which all the movable equipment and reserve supplies for battle are kept ready for use at a moment's notice.

B. **Supplies.**—(*a*) The **peace time allowance** has been carefully and generously calculated upon the actual requirements indicated by

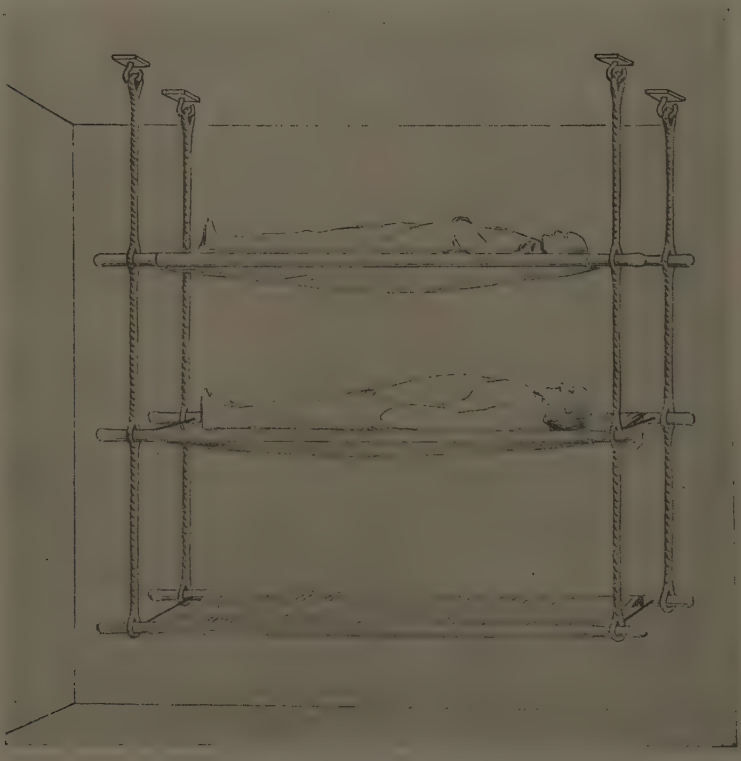


FIG. 50.—ARRANGEMENT OF STRETCHERS FOR INCREASING ACCOMMODATION FOR SICK AND WOUNDED AT BATTLE DRESSING STATIONS. (McDonall.)

years of observation, both as to inclusiveness of the official list and the quantity of each article. A unit of complement (75) is taken as the basis, and the allowance for a given ship depends upon the multiple of this unit represented by its total complement under ordinary conditions for a period of three months. While the allowance table does not include every article—drugs and appliances—found useful to medical science, changes in the official list and in the composition of listed items are made whenever advantage will result in the care of the sick and injured, and any article considered indispensable by individual medical officers is always allowed on request. For such of these sup-

plies as are meant for ordinary medical department service with a broad margin of safety there is a large central medical storeroom located on one of the lower decks convenient to the sick bay.

(*b*) **The War Reserve Chest.**—For the stores of the kind and estimated quantity primarily intended for use in battle, the storerooms above mentioned as constituting a part of the battle dressing stations are provided. The stock in the central storeroom replenishes and supplements them, but the battle storeroom stock itself is kept strictly in reserve for the emergency of battle. It consists of the following classified articles*:

Medicine.	
Adrenalin	1 bottle
Alcohol	500 c.c.
Argyrol or silvol (10 per cent.)	1 ounce
Aromatic spirits of ammonia	1 bottle
Boric acid, powdered	1 "
Boric acid ointment	½ "
Chloroform	6 bottles
Chlorazene	6 "
Flexible collodion	6 "
Fluid extract of ginger	1 bottle
Iodin, crystals	2 bottles
Iodin, tincture (7 per cent.)	1 ounce
Liquid petrolatum	1 bottle
Paraffin wax compound for burns	2 packages
Peroxid	3 bottles
Sodium carbonate	1 bottle
Soft soap	2 jars
Antiseptic and Disinfectants.	
Cresol	4 bottles
Phenol	1 bottle
Bichlorid of mercury	2 bottles
Tablet Triturates.	
Saline transfusion	1 bottle
Morphin sulphate	1 "
Hypodermic Tablets.	
Atropin ($\frac{1}{100}$ gr.)	1 tube
Hyoscin	1 tube
Morphin and atropin ($\frac{1}{8}$—$\frac{1}{200}$ gr.)	1 tube
Morphin and atropin ($\frac{1}{4}$—$\frac{1}{100}$ gr.)	1 tube
Nitroglycerin	1 tube
Strychnin sulphate ($\frac{1}{30}$ gr.)	1 tube
Surgical Instruments and Appliances.	
Case, expeditionary, boat medical	1
Case, expeditionary, boat surgical	1
Case, forceps, hemostatic	1
Dressing container	1 set
Catheter, soft-rubber	1 box
Inhaler, chloroform, with drop-bottle	1
Needles, suture, surgeons'	2 bottles
Shears, bandage	1
Sterilizer, electric	1
Syringe, hypodermic	1
Table, operating	1

* Largely from the excellent organization, Medical Department U. S. S. Mississippi, by Commander W. S. Pugh, Medical Corps, U. S. N.

Surgical Dressings.

Bandage, gauze, assorted	24	dozen
Bandage, flannel, 3 inch	24	
Bandage, muslin, assorted	28	
Bandage, scultetus	55	
Bandage, four-tailed	25	
Bandage, head	25	
Bandage, many tailed	30	
Bandage, T, 5 in each	30	
Bandage, triangular	10	
Compresses, gauze, 9 x 9, 25 in each	2375	
Compresses, gauze, 9 x 9, 20 in each	440	
Compresses, gauze, 8 x 10	88	
Cotton, absorbent	18	rolls
Dressings, large wound, 10 x 13	438	
Dressings, large wound, 9 x 10	1428	
Gauze, plain, absorbent	24	"
Gauze laparotomy pads, 4 x 16	15	
Gauze laparotomy pads, 12 x 12	20	
Ligature, catgut, plain, No. 1	9	tubes
Ligature, catgut, plain, No. 2	12	"
Ligature, catgut, chromicized, No. 2	3	"
Ligature, silkworm-gut, assorted	22	"
Packet, first-aid	106	
Pins, assorted	4	papers
Pins, safety-	4	dozen
Plaster, adhesive	6	rolls
Pouch, Hospital Corps, small	2	
Sewing outfit	1	
Splint, wire mesh for	8	yards
Splint, basswood for	24	
Splint, wood, large	12	
Tubing, rubber drainage-	12	
Wipes, gauze, 4 x 4, 20 in each	392	
Wipes, gauze, 4 x 2, 20 in each	392	

Dispensary and Laboratory Equipment.

Box, boat	12	
Brush, nail	4	
Measure, graduated, 250 c.c.	1	
Medicine-dropper	6	
Pencil, hair	6	

Hospital and Nursing Appliances.

Bag, hot-water	2	
Bag, ice-	2	
Basin, dressing, agate	4	
Basin, pus, agate	1	
Bucket, agate	4	
Close stool	1	
Cup, sputum, paper	1	package
Gloves, operating	4	pairs
Irrigator, agate, with fittings	1	
Irrigator, rubber, complete, F. S. type	2	
Medicine-glass	4	
Mug, agate	4	
Pad, operating rubber	1	
Pitcher, agate	5	
Razor	1	
Razor strop	1	
Thermometer, clinical	2	
Tongue depressor, wood	1	package
Tumbler	4	

Bedding and Linen.

Blanket	6
Gown, operating	6
Pillow cases, gum	1
Sheet, cotton	24
Towels, hand	36

Additional Articles.

Stokes' litters	5
Army litters	4
Cargo lamps (cluster and reflector)	2
Lamps, extra, Mazda (100 watts)	5
Gun bags	50
Candles	12
Matches	1 box
Binder boards	4 sets
Oakum pads, 8 x 12	148
Fracture pillows	7
Sponges, knit	46
Sponges, hand	124
Tags, white	88
Stock bottles, 1 gallon	8

Clerical Box.

Cord	1 ball
Carbon paper	2
Battle Station Casualty Report	50
Nomenclature	1
Form "N," Report of death	25
Medical history sheet	7
Form "F," Abstract of sick	50
Form "K2," Casualty Report	25
Form "G," Hospital ticket	25
Envelopes, large	25
Erasers	3
Penholders and pens	2
Pencils	2
Bottles, ink, red and black	2
Blotters	6
Diagnosis tags	12 dozen

In the above itemization attention is particularly invited to the bandages, shell wound dressings, compresses, wipes, and laboratory pads. These "ready-made surgical dressings" are standardized for the fleet and explicit instructions issued for their preparation from the quantity material included in the Naval Medical Supply Table. The manner of wrapping is also described. In anticipation of our participation in the late war thousands of these dressings were made up—enough to fill the war reserve chest of every ship of the fleet—by the Red Cross out of Navy material, and this would doubtless be a source of assistance in every emergency. Ordinarily hospital corpsmen make up all dressings. The large shell wound dressing, which has been changed as a result of a conference of medical officers since the publication of Vol. VI, will be described later.

2. Organization of the Medical Department on Battleships

A. **For Routine Work.**—Effective organization for the manifold duties under this head is an earnest of efficiency under battle conditions, and the most important factor in the attainment of the results desired

regardless of the numerical strength of the personnel involved is team work. The spirit of co-operation must be developed, and this necessitates a common understanding by every party to the organization of the duties of others, and in general the sum total of work to be accomplished by and the responsibilities of the medical department in the ship's make-up. Reading between the foregoing lines a principle comes to light, viz.: the rotation of the personnel in the duties of the department to prevent any tendency toward one-sidedness, to insure sympathetic comprehension of the other fellow's difficulties, and to prepare for all-round competence, interchangeability, mutual helpfulness, and therefore intelligent concert of action toward the single objective. As a preliminary to further consideration of this subject it is worthy of note that while the assignment of additional personnel may reasonably be expected in the event of war, no such organization as I am discussing can be sound unless based on the *normal* maximum of personnel. The head of the institution may then feel reasonably secure in his calculations and regard accessions in time of emergency as a welcome means of easing his problems and fortifying him against accidents and unforeseen developments.

As far as the several types of ships make it possible, the organization of their medical departments is fundamentally the same, based upon a standard formally promulgated. The allowed number of hospital corpsmen distributed among the different rates is in accordance with an officially established complement table which stipulates "for cruising ships, hospital corpsmen equal to one for every 100 persons on board. . . ." This is the peace footing allowance or the "normal maximum" above mentioned. It means 10 or 11 for the large ships, distributed as follows: 1 Chief Pharmacist's Mate, 1 Pharmacist's Mate, first class, 2 or 3 Pharmacist's Mates, second class, and 6 Pharmacist's Mates, third class. With these men and three medical officers, and a dental officer, the routine work of the medical department can be efficiently performed, and any ordinary emergency satisfactorily met when organized as above contemplated. Interesting as it might be, space does not admit the presentation of a representative battleship organization *in extenso* or even in outline; but some conception of it may be had by referring to the illustration showing the plan of the sick quarters and realizing that all medical department duties, except alone the professional care of those admitted to the sick list, must be fitted in with the incessant drills and the activities of other departments.

There is the work in connection with the care of cases of contagious diseases and of venereal prophylaxis and treatments; there is the work of the sick bay, the operating room, the dispensary, the dental office, the laboratory, and the storeroom; there is the work incident to scrupulous cleanliness of the compartments and sanitary supervision of the rest of the ship, of feeding the sick, of holding sick call, of caring for the physical property, of schooling the hospital corpsmen, of giving first-aid instruction to line officers and crew, etc., *ad infinitum;* then there are the ordinary emergencies of peace times in which the medical de-

partment plays its rôle—fire and rescue party, landing force, "man overboard," collision and abandon ship, etc.; and, finally, there are the events in repetition preparatory to belligerent activity—target practice, torpedo defense, and general quarters (strip ship for action). The Medical Department is organized for all this and strives for that perfection which comes with frequent practice and the acquisition of automatism.

B. **Preparation for Battle.**—Some general notion of this process has been given in the preceding paragraphs, which are in supplement to the information contained in Vols. IV and VI, and in the discussion of Battle Dressing Station. There seems little to add except in extension or modification of the specific subdivision of this heading as contained in the other volumes.

(*a*) **First-aid Instruction.**—It is sufficient to say in extension of this subject that there has long since been an awakening of interest in it on the part of officers and men throughout the service. The great probability that turret and secondary battery guns' crews and those stationed in the superstructure will be isolated from the attention of members of the medical department during action is now thoroughly recognized by other than medical officers and has inspired an ambition for independence in this respect. It has been found desirable for medical officers to supplement the instruction given by division officers to their men and to intensively instruct those groups likely to be isolated. Special attention is given to the latter requirement.

(*b*) **First-aid Provisions at Gun and Other Isolated Positions.**—The consideration of this matter follows logically upon the preceding paragraphs, and implies a means to the application of the elementary knowledge acquired by first-aid instruction. In the preceding volumes only brief reference to this subject is made, but the way is there paved for its further consideration by the recognition of the tendency toward increasing limitation to the scope of relief work. It is realized that the first-aid armamentarium for the purpose in view must be simple and strictly confined to material for the procedures taught, and that all must be proof against the possibility of inflicting injury from improper use in the excitement of the moment. It is for this reason that the propriety of including tourniquets is heatedly argued. There are weighty considerations in favor of their omission, but naval engagements are usually so comparatively short and the need of such a device at times is so imperative and useful in the unresourceful hand that the opposition has not yet succeeded in excluding the "instant rubber tourniquet." The other paraphernalia in the first-aid outfit for the use of the trained men of the deck consists of splints, bandages, cotton, boric or picric acid solution—the latter for fire- and engine-room—and large and small wound dressings.* The purpose of the tourniquet, splints, bandages, and shell wound dressings may be dismissed as self-evident. The boric acid solution is for smoke or gas-inflamed eyes;

* The wound dressing is an element of the first-aid provisions placed at gun positions which is common to all navies; other elements vary.

the picric acid solution is for burns; and the cotton is, among other readily conceived uses, for ear protection.

In the past various forms of containers for this equipment, as devised by individual medical officers, have been employed, but they were usually constructed of canvas and were otherwise of such insecure character against weather or meddlesomeness as to necessitate their being kept in store and brought out for drills or on occasions when their

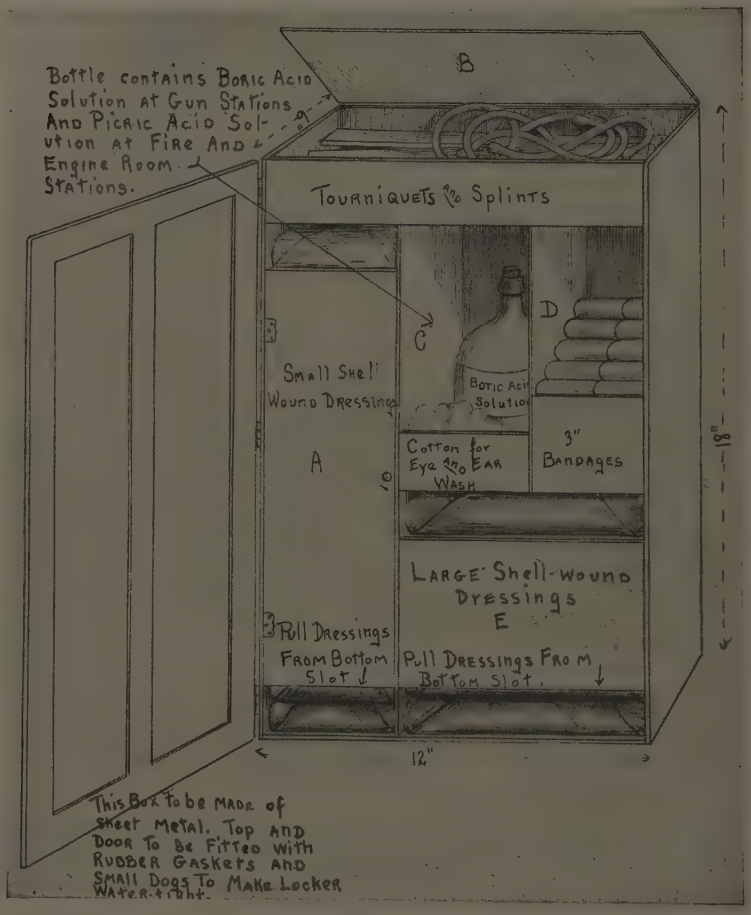

Bottle contains Boric Acid Solution at Gun Stations And Picric Acid Solution at Fire And Engine Room Stations.
B
Tourniquets and Splints
C
D
Small Shell Wound Dressings
Botic Acid Solution
A
Cotton for Eye and Ear Wash
3" Bandages
Large Shell-Wound Dressings E
Pull Dressings From Bottom Slot
Pull Dressings From Bottom Slot.
18"
12"
This Box to be made of sheet metal. Top and Door to be Fitted with Rubber Gaskets and Small Dogs To Make Locker Water-tight.

FIG. 51.—CABINET CONTAINING LARGE WOUND DRESSING AND OTHER FIRST AID PROVISIONS FOR GUN POSITIONS AND FIRE AND ENGINE ROOMS. (Owens.)

real need seemed imminent. Provision for this is now standardized in the form of a small steel cabinet fixed and kept under lock and key at the different positions indicated.* Figure 51 illustrates such a cabinet, which is designed in conformity with the several requisite characteristics.† It is water-tight, can be stocked to full capacity without

* The British, French, Italians, and Japanese have similar containers.

† Designed by Lieutenant-Commander W. D. Owens, Medical Corps, U. S. Navy.

danger of dislodgment when the door is opened, is so arranged that each article is easy of access, and that the removal of any one article does not lead to displacement or confusion of the contents. Everything is definitely placed and marked, and when a first-aid packet is withdrawn from the slot another automatically takes its place. The dressings are kept clean and dry. Pictures illustrating the application of tourniquets and dressings may be placed on the inside of the door.

(*c*) **Dispositions, Arrangements, and Supplies.**—This subdivision of our subject is reintroduced from Vol. IV only to say that in these later days the task involved in the feature of preparation for battle thus expressed is much less onerous. This is clearly evident from what has been said under Battle Dressing Station. The hurried assembling of equipment and supplies and the improvisation of arrangements for the reception of wounded and the observance of surgical technic is no longer necessary. In the main, everything required is always in place and ready, as should be the case—a part of the ordinary organization of the ship. Beyond this statement a clear understanding of the import and nature of the duties here devolving upon the medical department does not require that anything be added to what was set down in Vol. IV years ago. Of course, the personnel has been increased, and that eases the strain upon organization, and stretcher bearers* are now definitely assigned to the medical department for the purpose, and drill with it, and "receive such systematic continuous instruction as will make them next in value to the regular nursing force and of real and positive use."[28] This, indeed, has become such a fixed and logical policy that special attention is paid at training stations to the thorough instruction of bandsmen in first-aid methods and transportation, so that they fit in wherever they may go as the first reliance of medical department expansion in preparation for battle.

(*d*) **First-aid Dressings.**—No one single item in first-aid provision has been given more thought or brought out more suggestions than the shell wound dressing. This fact is due in large part to the seeming difficulty of meeting all the conditions (physical and surgical) and also to the variations in the conditions as conceived and urged by one or another surgeon. It has been a very unstable subject, and I only venture to introduce the latest modification of its form because, as above stated, it has been officially approved and become standard for the Navy. Early in 1917 there were probably as many different types of this dressing as there were ships of sufficient size to inspire the expectation of participation in belligerent activity. This constituted a situation which for many reasons seemed intolerable, and among others the fact that it was wasteful of valuable material and evinced a free-lance spirit in this one direction inconsistent with the demands of the times. A board of medical officers in the fleet was therefore appointed to consider and make recommendation upon that and other matters requiring standardization, and after examining all suggestions submitted and hearing the arguments pro and con, the following described "large

* All members of the ship's band.

wound dressing"* was adopted and recommended, with the result above stated:

"The shell wound or large wound dressing consists of a gauze pad 16 layers thick and 8½ to 9 by 10 inches, held in place by a four-tailed bandage, and is made as follows: From the standard gauze roll of four thicknesses and 8½ to 9 inches wide, cut off at a length of 40 inches. Fold the free ends over so that they meet in the middle. Now fold a second time along the line where the free ends meet. The length has thus been reduced to 10 inches, and the thickness increased to 16 layers. Tear off a piece of unbleached muslin 9½ by 60 inches. Lay the gauze compress in the center of the muslin and fasten it there by sewing along the sides toward the binders and diagonally from corner to corner. Each free end of the unbleached muslin is now torn down the middle to the pad so as to give a four-tailed bandage. Fold the dressing along the center by its short dimension so that the gauze is on the inside, the muslin binders on the outside. Now fold the upper tails on themselves

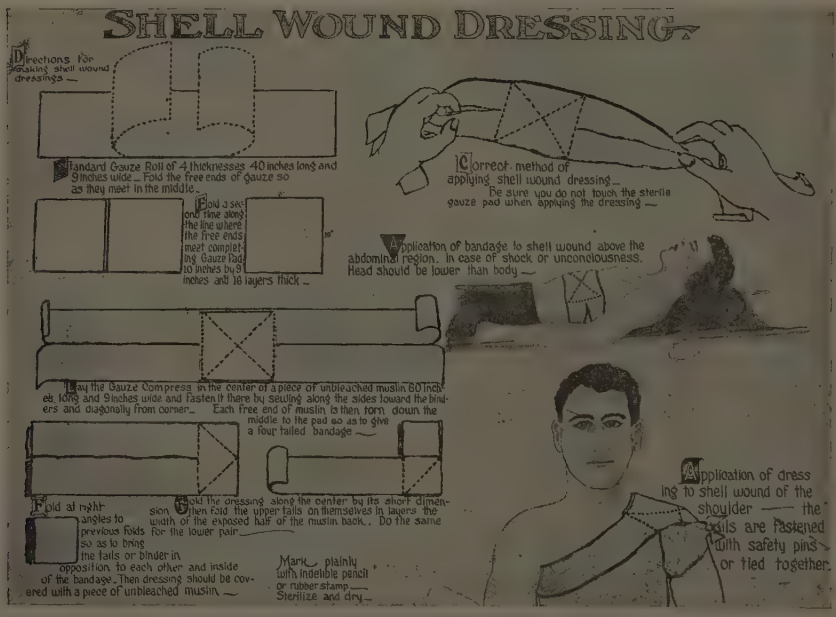

SHELL WOUND DRESSING
Directions for making shell wound dressings —
Standard Gauze Roll of 4 thicknesses 40 inches long and 9 inches wide — Fold the free ends of gauze so as they meet in the middle —
Fold a second line along the line where the free ends meet completing Gauze pad 10 inches by 9 inches and 16 layers thick —
Correct method of applying shell wound dressing — Be sure you do not touch the sterile gauze pad when applying the dressing —
Application of bandage to shell wound above the abdominal region. In case of shock or unconsciousness. Head should be lower than body —
Lay the Gauze Compress in the center of a piece of unbleached muslin 60 inches long and 9 inches wide and fasten it there by sewing along the sides toward the binders and diagonally from corner — Each free end of muslin is then torn down the middle to the pad so as to give a four tailed bandage —
Fold at right angles to previous folds so as to bring the tails or binder in opposition to each other and inside of the bandage — Then dressing should be covered with a piece of unbleached muslin —
Fold the dressing along the center by its short dimension Then fold the upper tails on themselves in layers the width of the exposed half of the muslin back — Do the same for the lower pair —
Mark plainly with indelible pencil or rubber stamp — Sterilize and dry —
Application of dressing to shell wound of the shoulder — the tails are fastened with safety pins or tied together.

FIG. 52.—MANNER OF MAKING AND APPLYING SHELL WOUND DRESSING.

in layers the width of the exposed half of the muslin back. Do the same for the lower pair. Once more the dressing is folded, but now at right angles to previous folds, so as to bring the tails or binders in apposition to each other and inside the whole. Cover with a piece of unbleached muslin, 12 x 12 inches, wrapping like an ordinary parcel and securing with a couple of stitches. Sterilize and dry. Wrap in oiled muslin or paper. Six to a dozen of these dressings may be wrapped together in canvas and kept at each gun station in a metal box secured by padlock and key. The container should be fastened to a bulkhead adjacent to but out of the way of the gun's crew.

"It will be advisable to have at dressing stations a certain number of shell wound dressings of larger dimensions than those given. These will not be distributed to the guns' crews. The dimensions recommended are 10 x 13 inches and each pad should be of 32 thicknesses of gauze." (Manual for the Medical Department of the U. S. Navy, 1917, Paragraph No. 1003.)

* At the same time the characterization was changed from "Shell Wound Dressing" to "Large Wound Dressing."

No matter where an officer or man is transferred, he is familiar with this provision for his relief because made up in uniform fashion on every ship and station. This too has made possible the complete training of bandsmen as first-aid assistants as well as stretcher bearers at other places than the ships on which they are ultimately to serve. An element of consideration in the adoption of this new type had to do with the service of marines ashore and the increasing percentage of large wounds in land operations as a result of the part played by heavy guns and bombs. The small first-aid packet was not calculated to meet all contingencies, and it seemed important, therefore, that the soldiers of the Navy should each be provided with a large wound dressing packet as well as the small first-aid packet.

(*e*) **Flash-proof Clothing.**—General comment on this subject was made above. The British issued it as a result of the battle of Jutland and other actions. It includes the following articles: Antiflash helmets, long gloves (known as Fearnought gauntlets), and jackets and trousers

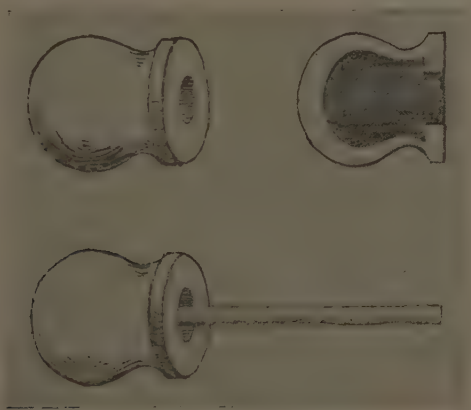


FIG. 53.—EAR PROTECTOR "BRITISH 'TOMMY.'" (From U. S. Naval Medical Bulletin.)

(known as Fearnought suits). These are made of heavy wool and before issue are treated with a fire-proofing solution the composition of which is 1 pound ammonium phosphate, 2 pounds ammonium chlorid, and 1½ gallons of water. The helmets and gloves are supplied for the whole ship's company; the suits are supplied to fire brigades and repair parties.

(*f*) **Protection of the Ears.**—This subject and its solution has acquired new and added interest as well as greater difficulties by virtue of the employment of corrosive and noxious gases in warfare and the need of "aviators and others obliged to work around aëronautical engines." British, French, Italians, and Americans have studied it, and all have contributed valuable information. Guild, of Ann Arbor, is probably the pioneer in this country, and Trible and Watkins,[29] of the United States Navy, and Richardson, of the United States Army, have conducted exhaustive tests of most if not all of the many ingenious devices which have been suggested for the purpose. The conflict of

ideas and the scientific facts which they have developed have no place here. Causes and effects will probably be presented in other chapters. It is sufficient to note that some form of protection is regarded by all as important and that the consensus of opinion inclines to the simple and inexpensive expedient of cotton or cotton-wool impregnated with vaselin. At the same time it is noted that the affinity of mustard gas for fats and oils makes the employment of this combination useless in the presence of that gas, and the employment of cotton alone, while the most practical measure, is rather ineffective. The British "Tommy," here illustrated, is for these reasons now recommended by the students of the subject in the Army and Navy, and all other devices are superseded in its favor.

(*g*) **Gas-masks.**—The training of men in gas defense consists in acquainting them with the nature of gases used in warfare, the care and use of the gas-masks, and drills in the handling of the mask, especially in simulated action. The rules and regulations for gas defense aboard ship provide storage space for gas-masks at the more appropriate locations and in the most suitable manner as regards accessibility, as well as preservation of good condition and efficiency, and they provide means whereby on simultaneous alarms in every part of the ship all hands put on and take off their masks. These rules also provide means for evacuating gas-laden air from contaminated compartments.

"The gas-mask consists of an impervious cloth fabric with rubber bands attached to keep it fixed tightly on the face, and fitted into this fabric are eye-pieces, a nose-clip, and a mouth-piece. The nose-clip prevents breathing through the nostrils, and all breathing is done through the mouth. The inhaled air is filtered through a canister, fitted on to the mouth-piece, containing layers of different substances which eliminate the gases used in warfare. The exhaled air goes out through a rubber flap valve which closes on inspiration, preventing any contaminated air from being inhaled. The main points to insure that a gas-mask will do what is expected of it when the occasion arises is to see that the fabric is absolutely intact with no holes in it, particularly at the attachments of the retaining tapes, eye-, nose-, and mouth-pieces; to see that the canister containing the filtering chemicals is in good shape and has not been exposed for any length of time to air vitiated with gas; and to see, above all things, that the rubber flap valve is not torn or otherwise injured."*

C. **Conduct of the Medical Department During Battle.**—(*a*) **Scope of Relief.**—The renewed emphasis I have placed upon the importance of first-aid provisions on the line of fire (turrets, casemates, conning tower, etc.) and of thorough first-aid instruction is an indirect composite expression of the views held by students of the subject in all the naval powers of the world, and is indicative of the realized contracted scope of the possible relief by the medical department itself during action. The most recent experiences place the so-called "Relief

* The personal notes of Lieutenant-Commander R. H. Laning, Medical Corps, U. S. Navy.

Stations," which the naval surgeon in the past was wont to make a part of his provisions, in a theoretic light, and have determined a dependence upon the armor-protected battle dressing stations* (one forward and one aft) as the only posts for medical department personnel. It is important that these spaces be so selected or arranged that movement of medical activities in them from one side to the other according to the battle-engaged side will be possible in order to secure the additional protection of turrets or other structures. From these central posts relief parties operate, making their excursions as summoned or as circumstances permit, and it is therefore apparent that the first-aid provisions for the use of the crew placed in cabinets at gun and other isolated or exposed positions become in themselves the first-aid stations or relief stations. This is a marked simplification in the program of the medical department forced by conditions of which not the least insurmountable is the absolute need to maintain water-tight integrity by keeping hatch covers and doors closed.

The hard but fixed doctrine of first aid during battle aboard ship is that humanitarian considerations are secondary to the success of the fight, and that as long as the ship is engaged nothing should be permitted to interfere with the effectiveness of its guns or the safety of the ship as a whole. On the other hand, the lives of those in the surgeon's division should not be endangered by being unnecessarily summoned to exposed positions. This must be clearly understood as a guide to both parties concerned, and that in general the wounded will have to dress themselves or be attended by shipmates at their posts of duty. Officers and gun captains must be taught to realize that, in the interest of maintaining the numerical efficiency and morale of the guns' crews, they must not lose their heads in the presence of the wounded; that slightly wounded men are to be given first aid and kept at their posts; that men wounded in such a way or to such an extent as to be of no further use at their guns, but who can walk, are to be given first aid and directed to find their own way to the nearest battle dressing station†; that the seriously wounded are to be dressed and laid aside out of the way until after battle or a lull in action; and that the dead are to be similarly laid aside. Whenever possible, seriously wounded should be announced to the dressing stations, and if, with due regard for the primal considerations, they can be recovered, this should be done, but it cannot be expected that the wounded thus announced can be immediately reached by the stretcher parties.

(*b*) **Disposition of the Wounded.**—This becomes apparent from the foregoing and what has been said on the subject in previous volumes. It is sufficient to add that the identification of the dead or seriously wounded and others and the preparation of the battle station casualty record is simplified and given accuracy by the individual identification tag worn by every officer and man.

* The French call them "battle hospitals."

† In every part of the ship direction arrows are plainly painted on the bulkheads indicating the route to the nearest battle dressing station.

(*c*) **Transportation.**—The methods vary as heretofore, and there is nothing particularly new to add beyond what has been said relative to the need created by the size of the manholes in hatch covers for stretchers of correspondingly small short-axis dimension. The stretcher parties are taught to bear in mind the necessity of maintaining the fighting efficiency, and that in responding to a summons they need not necessarily bring the wounded man to the dressing station. If only slightly wounded and able to remain at his post, they may dress his wounds and leave him there, but if it is decided to take a given wounded man to the dressing station he is to be transported—not necessarily in

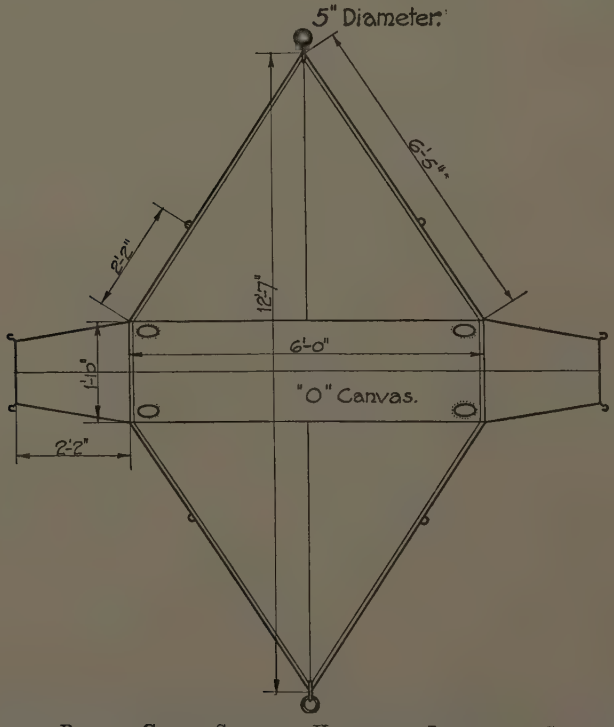


FIG. 54.—GENERAL PLAN OF CANVAS SLING FOR HAULING OR LOWERING A STRETCHER OVER THE SIDE OF THE SHIP. (From U. S. Naval Medical Bulletin.)

a stretcher, but in the manner which, while consistent with his needs, is *most expeditious*. In most cases this means by some manual—one-man, two-man or three-man—method, although in general it may be said that the splint stretcher (Stokes) has lost none of its favor in the United States Navy. (See Vol. IV, pp., 1066, 1067.)

D. **Conduct of the Medical Department After Battle.**—The urgency of gathering in the wounded, making record of the cases, attending to their needs and evacuating them to hospital ship or ashore as soon as possible after battle is rather too self-evident to require verbal emphasis, and there is no modification to make in what was said in previous volumes except as automatically made in deference to

the urgency expressed for the duties above enumerated. Medical Department "activities are at a dead center when battle tactics begin, but with the cessation of action its greatest work commences."[30]

Numerous types of appliances to meet the requirements of evacuation are used or have been suggested, and all display ingenuity. Among the newest of these the "canvas carrying cot" and the "canvas sling"[31] for ordinary stretchers make the greatest appeal. The description and uses of the former are given under Water and Land Transportation. The latter, while designed for the Army (British) litter to facilitate its transfer when laden to or from ships is a device not without usefulness in the Navy, particularly in view of the part played by the Medical

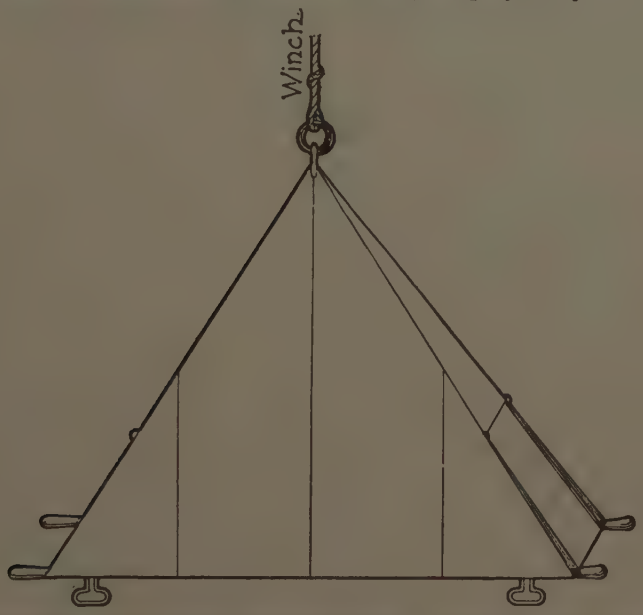


FIG. 55.—STRETCHER IN CANVAS SLING READY FOR HOISTING. (From U. S. Naval Medical Bulletin.)

Department of the Navy in handling the Army sick and wounded on transports. In abstracting Falkner's original article the contrivance was described* by Fauntleroy and Old, and is here illustrated with their

* "The contrivance is composed of "0" canvas, 1-inch pliable wire rope, two 5-inch iron rings, and four small hooks to secure the end flaps (Fig. 55). Wood does not form any part of the sling, and we are satisfied that it should not do so.

"The base measures 6 feet, 10 inches by 2 feet (6 feet by 1 foot, 10 inches for the United States Army litter), just sufficient to cover the under surface of the regulation stretcher, and allow its four feet to enter the round holes at each end (changed to oblong in sketch to take feet of United States Army litter).

"From ring to ring the sling measures 12 feet, 9 inches, while 2 feet, 2 inches is a good length for the two end flaps. These flaps are hooked up to four eyelets located on the edges of the triangular sides, so that they pass between the stretcher handles when the stretcher is in position, and the iron rings are approximated to take the winch hook.

"The diagram (Fig. 56) illustrates a complete circumference of wire rope for the body of the sling. It should, of course, pass inside a casing of canvas and not be merely sewn to the edges of the cloth; it takes practically the whole weight of the stretcher."

modifications to adapt it to the United States Army regulation litter. The United States Navy is of the opinion that for all-round usefulness and safety in the handling of all kinds of disabled, ranging from the

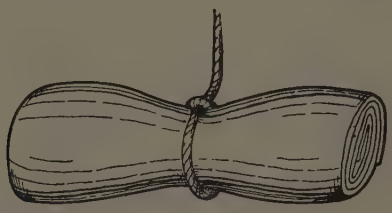


FIG. 56.—EMPTY SLING DONE UP FOR LOWERING. (From U. S. Naval Medical Bulletin.)

sick to the seriously injured or wounded, and for handling them in a surgically correct manner under the difficulties of seagoing requirements, nothing better or quite as good as the splint stretcher (Stokes) has

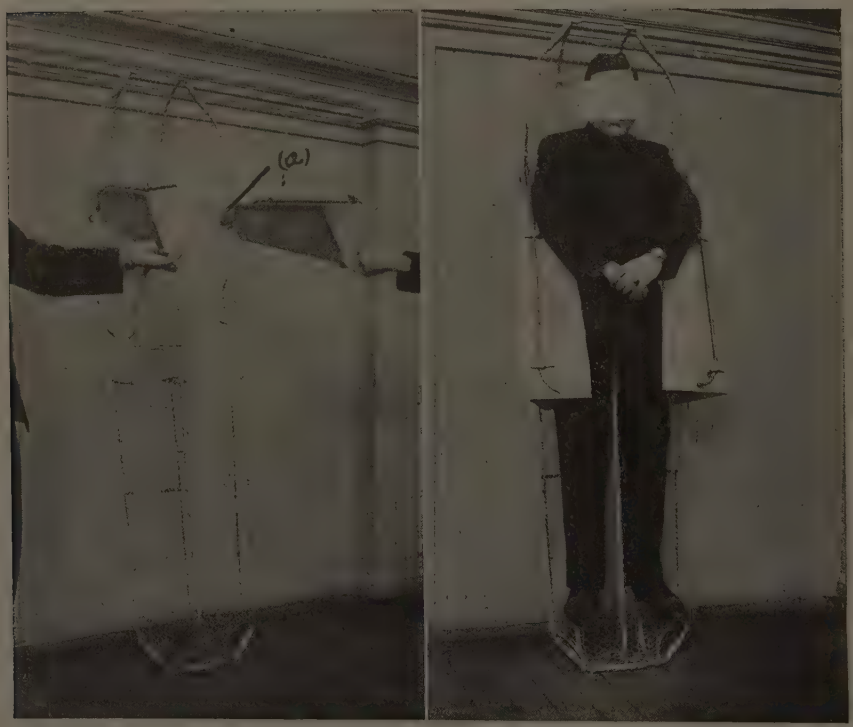


FIG. 57.—THE SPLINT STRETCHER (STOKES) FITTED WITH AIR CHAMBERS. (From U. S. Naval Medical Bulletin.)

been devised. A slight modification of this stretcher by the addition of air chambers has recently been suggested,[32] with a view to giving it the buoyancy which might at any time be required, and which seems not to be conferred in the essential balanced manner by life-preserver

jackets put on the patient and in the stretcher for the purpose. The

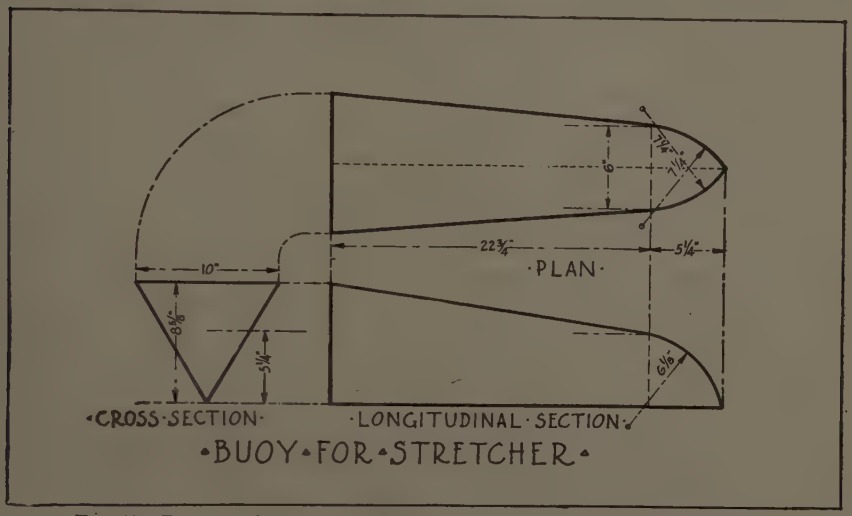


Fig. 58.—Plan and Buoy for Stretcher. (From U. S. Naval Medical Bulletin.)

particular field for the employment of this device would be on those stretchers being used to transfer patients from or to ships.

V. HOSPITAL SHIPS

The physical relationship, the structural features and equipment, and the organization and internal functioning of the hospital ship have already been given the attention space allows. It remains briefly to discuss the newly developed conception of its functional relationship to the fleet and its duties and possible service in peace and war.

As stated on page 1071 of Vol. IV, "there is hardly a need to discuss the functions of a hospital ship in time of peace"—yet, on this same page and in the same paragraph, the following appears: "they would represent economy to the Government in the transportation of the . . . disabled to base hospitals. . . ." On the other hand, on page 781 of Vol. VI it is stated, "each fleet must . . . include in its organization a hospital ship to remain with it or in its vicinity at all times . . . during the long periods of peace and in war. . . ." These conflicting statements cease to disturb when viewed in the light of their respective dates, for the latter represents progress out of experience in a lapse of three years and the idea it expresses has been further confirmed by recent experience. Indeed, it constitutes the only new matter which need be considered here and which was touched upon under Water and Land Transportation.

"The hospital ship, as before stated, is merely a floating hospital—a vessel equipped with everything that pertains to hospital use for the care of the sick and injured, whose duty it is to attend* the fleet at its

* It should remain at the fleet base, accompanying the fleet whenever change of base is made.

base and care for all cases of illness and injury originating in the fleet, which may, with a fair degree of certainty, soon be able to return to their duties on their respective ships. It is not a part of the function of the hospital ship to transport sick and wounded from the fleet to a base hospital ashore, nor is it a part of its function to transport sick and wounded across the ocean."[33] It is the opinion of Blackwood, furthermore, that the function of a hospital ship should not be expanded to include the care of any very large number of cases of contagious disease because, in addition to other very obvious reasons, its capacity is then quickly absorbed and its utility as a general hospital—its legitimate function—seriously embarrassed, if not destroyed.*

In time of war the fulfilment of her function as outlined by certain articles of the second Hague Conference is found beset with such difficulties, incident to the developed conditions and instruments of modern naval warfare, and questions of interpretation[30] that the dross of theory is finally brushed aside and facts arising out of experience and observation now constitute the basis of decision in this much discussed matter. Germany's disregard of the neutrality of the hospital ship is notorious and has given not only food for thought, but occasion for hesitancy and caution. "Armistices are not unknown in battles ashore for the purpose of removing the dead and wounded, but no instance of a mutual suspension of hostilities at sea for this purpose is known, and probably none will occur." The fairly wide-spread conclusion of those qualified to speak with any authority on the subject is that in time of war the function of the hospital ship remains about the same as in peace, and that, contrary to general belief, "she cannot be used to remove the wounded from ships coming out of action; nor can she at any time be anywhere in the neighborhood of action, or of any elements of the fleet . . . preparing for such action."† A fleet maneuvering preliminary to action must do so with the greatest secrecy. Just the opposite obtains in the case of the hospital ship. She must at all times, day and night, advertise her identity to maintain her right to protection under the Hague Convention. She is unable to sail with the fleet because of her slower speed, and even if this were not the case, it is highly undesirable that she should do so, as her appearance would suggest the proximity of the fleet. There is nothing about the practical realities of battle at sea in this age to invite the presence of a hospital ship as offering anything in the way of practical assistance, and her case as regards the needs of the fleet immediately after action is not much better. She loses nothing of her actual importance because of these facts. She continues to be the backbone of the medical department in the care of the personnel of the fleet.

* Every fleet should have, in addition to a hospital ship and an ambulance ship, a contagious disease ship arranged and equipped according to the principles of an ordinary contagious hospital ashore.[33]

† Unpublished paper, Captain N. J. Blackwood, Medical Corps, U. S. Navy.

VI. TRANSPORTS

In medical department organization and preparation the one not long foreseen duty, in connection with the conduct of the late war, was the care of the Army as well as of the Navy sick on board the troop transports. The problem of transporting the American Army overseas and back fell largely to the Navy, and the records attest the efficiency with which this undertaking was accomplished. In less than fifteen months from our entrance in the war the number of troops transported had passed the 2,000,000 mark and approximately 45 per cent. of the total was sent over in vessels manned and operated by the officers and men of the United States Navy. These vessels, which came eventually to number some 94 of the largest merchant ships out of a total of 387 operated by the Navy, comprised what was known as the Transport Force—a part of the Navy Cruiser and Transport Force including transports and convoying ships. The repatriation of the overseas forces fell almost entirely upon the Navy, and among the troops returned from France and elsewhere there were approximately 130,000 sick and wounded and insane to be cared for by the Medical Department of the Navy.

The Bureau of Medicine and Surgery of the Navy Department very early in our belligerency "saw that the care of the Army sick and wounded on the high seas would eventually fall under its supervision, and that the work in the sick bays of these vessels would necessarily be carried on by the medical officers and hospital corpsmen of the Navy." Steps were immediately taken to organize and make material provisions for this unusual duty and the personnel was carefully selected for the purpose. The Medical Department of the Navy saw to the installation of properly furnished sick accommodations, and itself provided doctors and hospital corpsmen and medical and surgical equipment and supplies sufficient adequately to care for the Army sick on the eastbound voyage and for definite quotas of Army sick and wounded on the west bound voyage of the vessels of the transport force.[34] All that was done in the matter of organization and work in an experience covering two years and more is now on the books as a part of medical department responsibility and constitutes the basis for (if not the complete plans of) operation, should the future bring the need again to transport large bodies of men to and from overseas fields of campaign. The data so formulated consist of: a complete list of furnishings, equipment, and supplies required and the source from which to be obtained; arrangements and facilities for fumigation and other sanitary preparation of the ship between voyages for the reception of fresh troops; complete instructions for the maintenance of hygienic and sanitary conditions during voyages; a system of vermin and venereal inspection and delousing; a program of social hygiene instruction; a plan for the control and management of communicable diseases with provision for disinfection; a system of sick call and receiving and caring for sick and wounded; instructions for the co-operation of the Army personnel in maintaining sanitary conditions and caring for those hospitalized; detailed require-

ments in the care of the dead; and a schedule of the clerical work involved and the forms and reports required. The policy of vacating between-deck spaces for aëration and thorough policing and getting the troops on deck at least twice a day is considered very important.[35]

Of course, the homeward voyage with sick and wounded is the larger and more important phase of the duty from the medical department point of view, and when the tide of transportation turned in this direction, additional provision had to be made in the way of increasing sick capacity, medical personnel, and medical equipment and supplies.

Each ship is rated according to its sick carrying capacity, and this information is communicated to the Commanding General of the American Expeditionary Force in such a way as to show the accommodations available for special classes of cases, so that he may know the classes of patients and the number of each that can be embarked on a given transport. Except for a relatively few special cases in which transportation by commercial liners may be admissible, all sick and wounded are repatriated on ships operated and controlled by the Navy—hospital ship or transport—whichever is most suitable and available. The Army is charged with the embarkation and debarkation of patients; the Navy, with the control and care of the patients while on board, the Army upon request rendering such assistance in personnel and material as may be necessary. The remains of all men dying at sea, whether en route to or from the United States, are embalmed and returned to the United States, and each transport is furnished with the personnel and equipment necessary to this care of the dead.*

The medical organization of the transport service consists of a Force Medical Officer as its head located centrally or at the largest and busiest port, with a direct representative at each port of embarkation and debarkation. The latter is responsible for carrying out his chief's policy in general, though acting independently in the event of emergency or unforeseen conditions. It is his duty also to keep the transports arriving at his port of duty fully stocked with medical supplies and to arrange with the Army representative as soon as advanced information is received as to number and character of cases for the debarkation of the Army sick and wounded.

The medical department of each ship looks to him in all matters concerning its work requiring professional assistance and is subject to his inspection and general supervision, and to his direction as regards questions of policy.

The organization and conduct of the medical department aboard a transport comes directly under its Senior Medical Officer who is alone responsible to the Force Medical Officer for loyalty to policy and efficient results. For the work of his department he is allowed a varying number of assistants—from two to five, depending upon the size of the ship—a dental surgeon, a pharmacist, and a number of hospital corpsmen of lower rates calculated upon $1\frac{1}{3}$ per cent. basis of the ship's carrying capacity. With the large number of patients to be cared for

* Unpublished report by Commander J. J. Snyder, Medical Corps, U. S. Navy.

the work itself is usually organized on a hospital routine, but this is as the Senior Medical Officer elects.

A medical liaison officer acts at the port of embarkation of wounded to insure such selection of patients for embarkation as will fully and to best advantage employ the available capacity of medical accommodations on transports.

VII. NAVAL AIR SERVICE*

In the matter of physical requirements for aviators there seems to have been a tendency toward elaborating tests and an unreasonably high standard, from which without perceptible practical effect as yet reaction is evident among the closest students of the subject. The quest for the superman has been particularly marked in the United

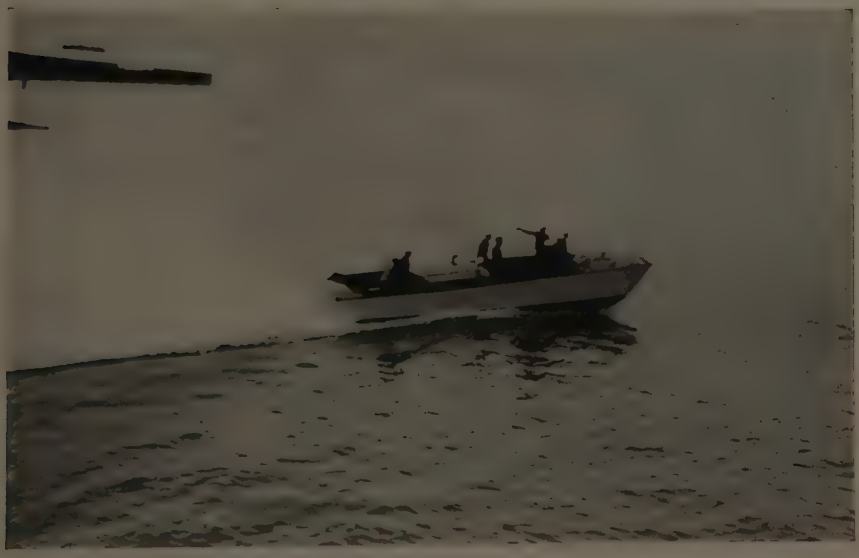


FIG. 59.—AIR SERVICE, MEDICAL DEPARTMENT—SPEEDING TO SCENE OF ACCIDENT.

States. It is unfortunate, because unnecessary and wasteful of flying material, as experience has shown little relation between the physical perfection sought and the reactions of the avaitor in actual flight. Unquestionably, physical fitness is an important qualification in an applicant, and a properly conducted examination involves many new points more or less in acknowledgment of the unusual occupation and environment concerned, but flying is a new science and hitherto unstressed faculties and temperamental characteristics are called into prominence.[36] However important the physical examination may be, it is certainly far from being infallible as a criterion of eligibility. There is an indefinable "something else"[37] of psychologic import which is,

* Much of this section is taken from an unpublished paper by Lieutenant A. M. Stevens, Medical Corps, U. S. N. R. F.

at least, counterpoising as a factor in the real problem, which is to find men who can learn to fly. This requires an estimate of all the qualities comprehended by perception, psychomotor reactions, and emotional control. These are being given laboratory and clinical study, and there is a wealth of information already available from English, French, Italian, and American sources* which the interested reader must seek elsewhere. Many valuable data are also available on the effects of high altitude flying, but this does not especially concern naval aviation, as sea planes ordinarily do not rise above the level of 4000 feet.

The question of a qualified aviator's fitness to fly at any time, from the point of view of intercurrent conditions such as illness or injury, shock, dissipation, loss of sleep, strain or fatigue, etc., is another matter, and involves the daily observation by a medical officer familiar with the behavior-characteristics of the individual members of the com-

FIG. 60.—ARRIVAL OF MEDICAL DEPARTMENT AT SCENE OF ACCIDENT.

mand and sensitive to variations in these as evidencing abnormality—temporary or otherwise. In this connection the policy of the Army in creating the office of "flight surgeon" seems excellent. These officers live and associate with the aviators constantly and in this way are able to quickly pick out those not in proper condition to fly.

There are, of course, numerous physically and emotionally trying conditions incident even to the low altitude flying of seaplanes, the bad influences of which must receive the preventive consideration of medical officers, and the peculiar hazards of oversea flying suggest special precautions and provisions for relief. Apart from such equipment as is concerned with the mechanics of a seaplane, certain essentials to protect or save the life of the flier, such as fire extinguisher, life preserver, first-aid packets, and emergency ration, etc., are carried.

* German data are not yet available.

As regards service conditions ashore, temporary water front sites, which may be dictated by military necessity, offer few of the required sanitary advantages and little opportunity for the necessary protection against hostile attack. The low ground precludes the construction of dugouts for personnel and even bombs and gasoline must be stored on or near the surface. As a result, the seaplane base in a war zone offers a compact target for enemy artillery or bombs with the maximum damage from each direct hit. The expectation of casualties is proportionally high.

Aside from the wounds due directly or indirectly to gunfire and bombs and the injuries due to the mechanics of aviation duty, there are casualties resulting from the fall of a seaplane which may be classified as follows:

Fig. 61.—Administering First Aid Before Taking Patient to a Shore Station.

1. "Those incident to a faulty landing. In this case the seaplane is traveling at low speed and the actual drop is short. Though the machine may be badly broken up, the crew usually escapes with minor injuries and a wetting.

2. "Those incident to a side slip on a turn. This type of accident is more dangerous, but if it occurs at a relatively low height, the banked planes strike the water first and, in a sense, absorb the shock of the fall, so that the occupant of the fuselage* may not be severely injured. At a fair height the seaplane in a sideslip very soon goes into a spinning nose-dive.

3. "Those incident to a nose-dive or tail-spin. This type of fall counts a very heavy number of fatalities. The prevailing type of seaplane, with its dead weight of underbody and forward engine, is nose

* Body of the aëroplane.

heavy to such a degree that once falling it is almost impossible to regain control and flatten out, as is possible with the Army plane. In the spinning nose-dive, the plane crashes into the water head on with terrible impact. In the pusher type of machine the engine breaks away and jams down against the forward cockpit, crushing the pilot. The usual cause of death in the case of observers is fractured skull, apparently from being thrown forward by the shock against the forward edge of the cockpit."

In routine particulars the organization of the Aviation Medical Department corresponds with that of any shore station. The first-aid station or dispensary is most useful when close at hand for emergencies and accidents, that is, near the water front and hangars, but if the seriously ill have to be kept on the Station, they cannot rest in face of

FIG. 62.—PATIENT IN SPLINT STRETCHER BEING TAKEN ABOARD SEA-SLED.

the noise of engines and propellers and the machine-gun target fire. Under usual conditions serious cases of illness and injury are evacuated to a base hospital. If this is not possible, the medical officer is faced with the added responsibility in the protection of the bed-ridden cases against bombing or artillery fire.

"A medical officer must be on watch at all times when seaplanes are in the air, prepared to go to the aid of a fallen machine. There should be a fast motor boat standing by in patrol hours provided with all requirements for first aid to the injured, dry blankets, hot coffee in thermos containers, grapnel, rope, wire cutters, and a short handled axe for use in clearing wreckage.

"When a plane crashes more than two miles out, the ambulance motor boat cannot be depended upon alone. In the first few minutes after the accident there may be men whose injuries are in themselves

not serious, floating unconscious or caught in a tangle of wire and broken stuts, and these men will drown unless help comes at once. The nearest plane in flight should come down at once to the wreck, effect immediate rescue, and stand by for the boat. In any case, an emergency seaplane, tuned up and ready to start on the signal, ought to be in readiness at the station when no other plane on patrol is within sight of a crash, or when a pigeon message or wireless reports a plane down out of sight. The medical officer is expected to go as forward observer, with the motor boat to follow as soon as possible.

"For the transport of the sick or injured to the base hospital a motor ambulance is required. This must be ready at a moment's notice whenever the planes have to skirt the coast or circle inland after getting off the water, or before volplaning into the wind. The air at low levels over buildings, hills, and woods is much more bumpy and treacherous than over open water, and the heavily built seaplane in a slow spiral over land is a decided risk."

VIII. RECONSTRUCTION AND REHABILITATION OF THE WOUNDED*

This wise movement in the interest of individual and national economic insurance, provided for by Congress, was promptly given practical expression in the Navy through the iniative of the Surgeon-general, who, in conferenc' with the Navy Department and the Federal Board for Vocational Education, drafted a plan for the care of those in the Navy contemplated by the law. In his letter to the Commanding Officers of all Naval Hospitals on the "Establishment of a combined curative workshop and subsequent vocational apprenticeship system at Navy Yards for reconstruction and rehabilitation of the wounded," the first paragraph reads: "It is highly desirable that reconstruction of physical defect or disability, adjustment of the mental state, restoration of function, and adaptation to former or other vocation shall be enhanced and initiated by the Medical Department during the convalescent period."

The plan as formulated and communicated to those responsible for its execution (Commandants of Navy Yards and Commanding Officers of Hospitals) and as it now exists involves the close co-operation of hospitals and yards, but looks very naturally and properly to the hospital side of the organization for guidance and control. Details of the co-operation are arranged between the above-mentioned naval authorities for the best interests of the plan and the patient, as governed by the existing circumstances in each locality concerned. The plan is outlined by the following:

* From official correspondence and orders.

NAVY CLASSIFICATION DISPOSITION

Received in Naval Hospital.

I. *Medical, surgical and special treatment.*

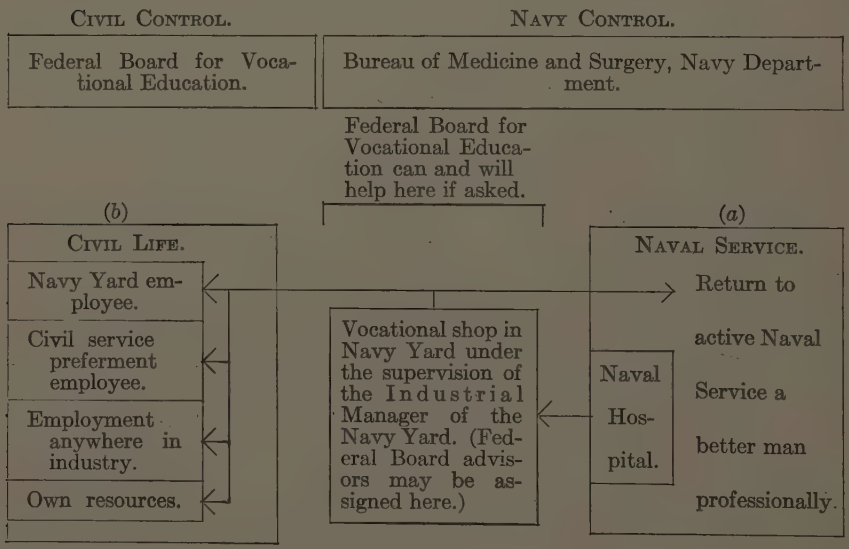
II. *Convalescent period.*
(1) Class at hospital physicotherapy exercises, ward work.
(2) Class at Navy Yard under Industrial Manager, occupational.
(*a*) Group still under medical supervision—Vocational advisor for Federal Board—work in shop.

Overlapping zone. Suggestions of Federal Board desirable.

III. *Duty.*
(*b*) Group not under medical supervision.
(*aa*) Group for return to service (duty).
(*bb*) Group for discharge from service who may continue yard work.
1. As civil employee special preferment.
2. As civil service preferment.
3. Anywhere in industry.
4. Own resources.

Received by Federal Board for Vocational Education.

SCHEMATIC DISPOSITION


Civil Control.
Navy Control.
Federal Board for Vocational Education.
Bureau of Medicine and Surgery, Navy Department.
Federal Board for Vocational Education can and will help here if asked.
(b)
(a)
Civil Life.
Navy Yard employee.
Civil service preferment employee.
Employment anywhere in industry.
Own resources.
Vocational shop in Navy Yard under the supervision of the Industrial Manager of the Navy Yard. (Federal Board advisors may be assigned here.)
Naval Service.
Return to active Naval Service a better man professionally.
Naval Hospital.

The plan, after carrying convalescent patients forward as far as facilities at hospitals make possible, utilizes the facilities at navy yards, first for preliminary training with a view to promoting physical reconstruction, and second, for vocational rehabilitation. The benefits sought are medical and industrial—both of such importance that the work is initiated at the earliest possible moment. Preliminary training is preponderatingly a therapeutic measure. Rehabilitation is preponderatingly an economic measure, including vocational readaptation or training for a new vocation through the agency of curative work-

shops and, while still under hospital treatment, giving patients occupational readjustment to industrial and living conditions. Navy Yards, where almost every form of industrial activity is found, are ideal institutions for the purpose.

The Commanding Officer of a hospital prescribes occupational training advisable as a therapeutic measure for convalescent patients.

The Commandant (Industrial Manager) of a Navy Yard, having ascertained what is needed, makes arrangements for the reception of individual or groups of patients, and provides various types of work, with access to suitable machinery and tools, which the patients may be reasonably expected to undertake satisfactorily and with advantage both to themselves and the shop.

The Federal Board for Vocational Education offers the services of its experts to assist in working out a proper plan of curative workshop training and its co-operation and advice in these and other respects is constantly used at hospitals and navy yards.

The work done in the shops by patients is supervised by a representative of the industrial manager (a workman instructor) or by a vocational advisor detailed, upon request, by the Federal Board of Vocational Education.

As a progression beyond the curative workshop there is established in co-operation with the Federal Board for Vocational Education a plan of vocational training for discharged disabled men of the Navy and Marine Corps to be given in navy yards or shops. The men who as patients received preliminary training in the curative workshop can thus carry on with a continuous process of prevocational and vocational training as provided by law. In this apprenticeship system the cost of all training approved by the Federal Board is assumed by it.

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CHAPTER X

SURGERY IN A FIGHTING SHIP*

By Surgeon Lieutenant-Commander Horace E. R. Stephens, F. R. C. S., R. N.

Plymouth, England

Naval surgery has already received its due meed of recognition in the form of two chapters in previous volumes of this work; and those peculiar features which naval warfare introduces to the domain of surgery have not materially changed since those lines were written. Looking further back through the historic records we find a literature so sparse in quantity and so meager in scientific detail that it seems almost valueless for our purpose; and yet, Sir William Beatty[1] in describing the musquet ball which killed Lord Nelson, writes: "On removing the ball, a portion of the gold lace and pad of the epaulette, together with a small piece of his Lordship's coat was found firmly attached to it." How little altered the conditions are today, from a surgical standpoint, when the blue serge or flannel of the sailor is dragged through his wound by the jagged edges of a splinter of armor-piercing shell.

The enormous increase in the size and range of modern naval guns, together with the improved methods of constructive protection in the diverse classes of fighting ships, rendered an exact knowledge of their effect upon each other impossible until war broke out. From the Spanish-American and Russo-Japanese Wars we obtained a glimpse of the future, but in the main our designs for operating on the wounded sailor were based on surmise which masqueraded as fact under the cloak of reality. To a certain extent, in view of the ever-changing types of warship, this state must always exist. The light from our recent experiences has enabled us to form a clearer perception of the limitations of surgical procedure under war conditions, and with such assistance we can determine how far these preconceived ideas have succeeded and in what respects they have failed. The following pages may be accepted as representing the general trend of opinion of those British naval medical officers who, after having passed through the ordeal of battle, have recorded their results. Their writings are frequently quoted in order to illustrate points of interest. It is true that many obscure problems still require elucidation and that several schemes in vogue at the present time will undergo considerable modification in the future. Nevertheless, although some of the details may not be received

*Published by authority of the Lords Commissioners of the Admiralty and of the Medical Director-General, Royal Navy.

with unanimity, the main principles advocated have at least been hall-marked with the stamp of active service practice.

Types of Ship.—In discussing this question we will consider only those ships which are built for the specific purpose of fighting, and leave out of account that heterogeneous fleet of liners, merchantmen, trawlers, yachts, and coasting vessels which the exigencies of war transformed into either offensive or defensive naval units. The history of

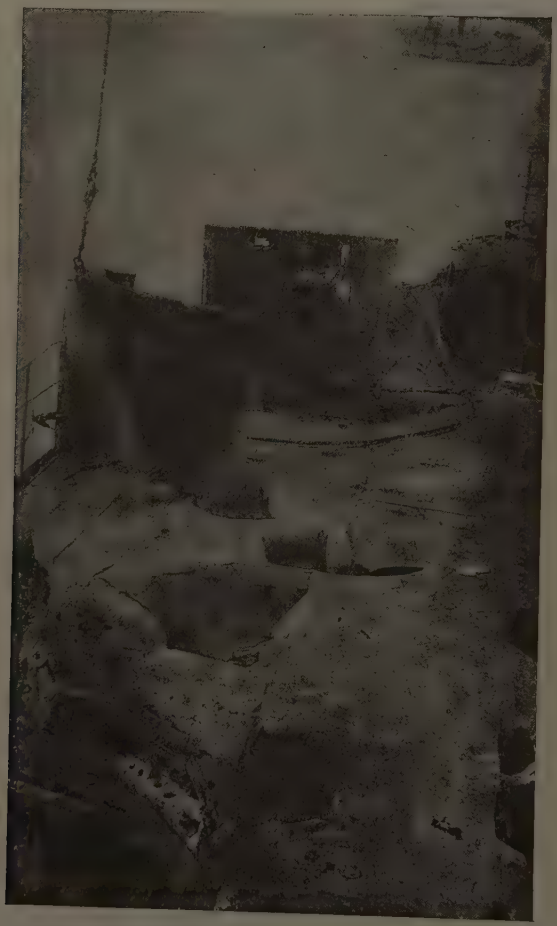

FIG. 63.—QUARTER DECK OF EMDEN, LOOKING AFT. PENETRATION OF THE UPPER DECK BY PROJECTILES FROM EXTREME RANGE IS EVIDENT. (Courtesy of Surgeon Lt. G. D. Ferguson, R. N.)

naval construction shows only too clearly how the power of the fighting ship has developed *pari passu* with the progress of industry ashore—an interminable process. However, it is not intended to trace the evolution of a modern ship of the line, but rather analyze the details, from the medical officer's standpoint, of the three principal types toward which naval construction tends to conform at the present day.

Such reflections as to whether the submarine or ships of the air

will eventually carry their surgeon are purely speculative, besides being outside the scope of this chapter. The claim of the monitor to be considered cannot be overlooked, but as yet this class remains so ill-defined that it may, with certain reservations, be included with the light cruisers. To what extent surgery is limited in each type may be gathered from a close study of their structure, their methods of fighting, and the effect of the enemy's projectiles upon them.

Battleship and Battle Cruiser.—For our purpose these may be considered as belonging to the same category. The former, however, possesses some undeniable advantages, in that her broader beam endows her with more accommodation for her complement; her heavier armor renders her less vulnerable; and her diminished speed tends to

FIG. 64.—ILLUSTRATING THE MODE OF ENTRANCE OF THE HIGH EXPLOSIVE SHELL WHICH WRECKED A MEDICAL DISTRIBUTING STATION SITUATED "BEHIND ARMOR." (Courtesy of the British Admiralty.)

lessen the vibration aft. The battle of Jutland proved that the decks of this class of ship could not withstand the penetrative power of the improved high-explosive shell. The increased range of heavy projectiles was also an important factor in this connection, since at the end of their trajectory the dropping or plunging shots fall almost perpendicularly, and thus add considerably to the casualties between decks (Figs. 64, 65, 66). Monitors which are hit by shells from heavy howitzers ashore are especially prone to this form of injury. Figure 64 shows clearly the mode of entrance of such a shell. This shell wrecked the foremost and main medical distributing station which is illustrated by Figs. 65 and 66. The significance of such incidents greatly influences the medical officer in working out his organization, especially the choice

of the most suitable stations for the first-aid parties. Later types of battleship show a different disposition of their armor, in that the thick protective deck in the center of the ship has been raised to the level of the main deck; this position, being well above the level of the deep load line, gives more protected freeboard in a damaged condition.

A modern battleship may be regarded as consisting of a honeycomb of compartments separated from one another by steel decks and bulkheads; these are connected with the upper deck by means of a series of hatchways and ladders, and communicate with each other by tunnels, alleyways, or water-tight doors. It is these "lines of communication," to borrow a military term, which are of such vital importance to the medical officer. Engine-rooms and stokeholds occupy the greater

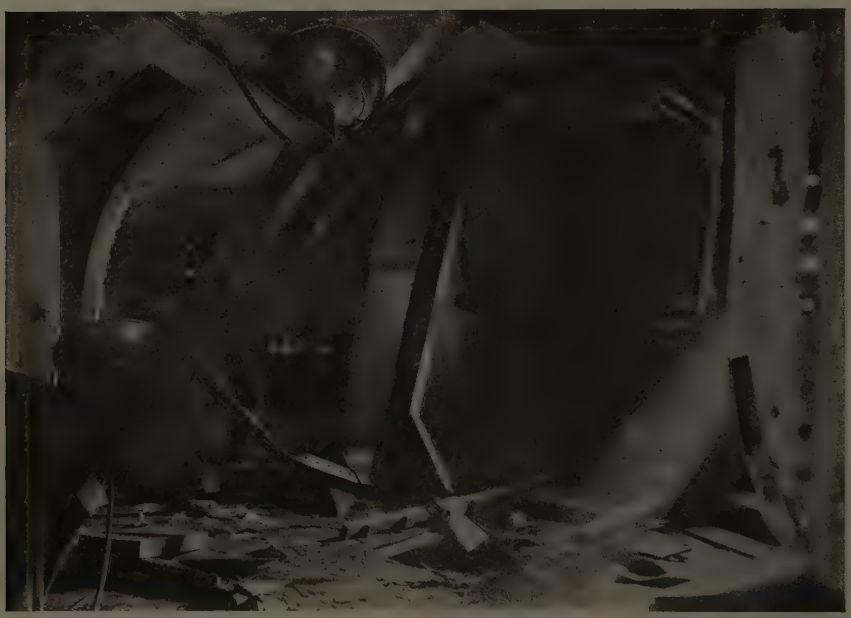

Fig. 65.—The Damaged Medical Distributing Station. (Courtesy of the British Admiralty.)

part of the space below the water-line; in addition, the trunks leading from the turrets to the magazines and shell rooms take up a large proportion of the remainder. Thus it will be seen that the provision of adequate medical distributing stations or an operating theater is fraught with difficulty.

In spite of these many restrictions the big ships, which prove steady in a seaway, offer the most suitable environment afloat in which a naval surgeon may accomplish that practice in which he has been educated ashore. Generally speaking, the scope of surgery in a fighting ship varies in direct proportion to her size and inversely to her speed.

The Light Cruiser.—The broad features of a standard type of this class are not easy to define, as the ideal design is still in the process of

evolution. Her greatest asset is speed, to which the utmost importance is attached. To further this end the heavy armor so characteristic of the former class is sacrificed. The large light cruiser carrying a powerful main armament cannot be said to have overcome the inherent difficulties in maintaining a high speed in heavy weather, and the smaller type has proved herself more adapted to meet the circumstances under which the recent war at sea was waged. It is this latter class which claims our particular attention. Her sides are protected up to the level of the upper deck with high tensile steel plating only $1\frac{1}{2}$ to 2 inches thick. Some possess slightly heavier armor, but these are built for ocean work in any part of the world and have a large radius of action. *Armored*

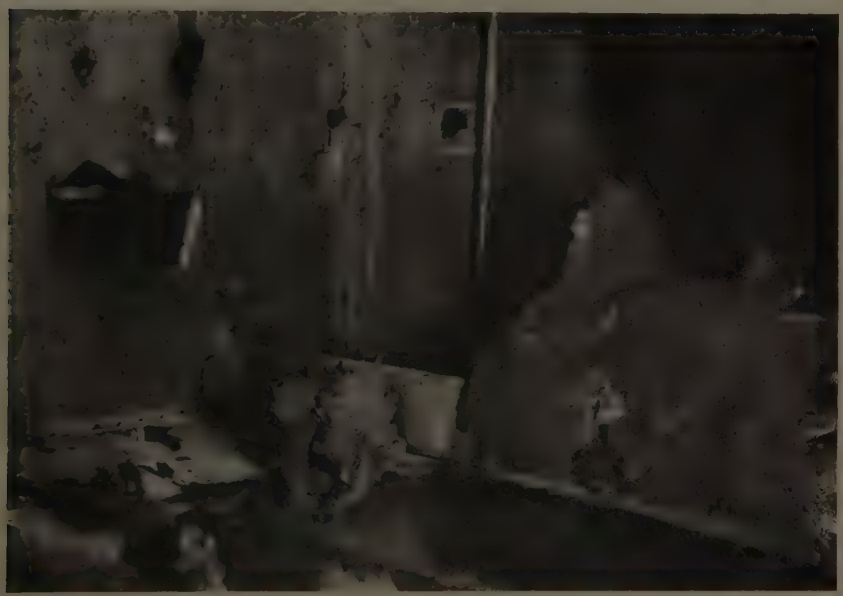

FIG. 66.—MORE DETAILED VIEW OF DAMAGE. THE TORN UP DECK AND GAPING HOLES ARE QUITE CHARACTERISTIC. (Courtesy of the British Admiralty.)

cruisers have been included in the list of statistics, but may be regarded as a prewar model and, therefore, hardly merit a separate description.

The hatchways and steep ladders militate against the easy transport of wounded; and passages below the upper deck are attenuated and have sharp angular turns. The exiguous medical distributing stations alone denote the lack of accommodation which is so keenly felt when the injured begin to arrive. At high speeds the vibration becomes excessive and abrupt alterations of the ship's course provoke a very appreciable list. In a heavy sea the pitching and rolling become pronounced. All these factors impede the work of the surgeon to a greater or less degree. On the other hand, in an equal fight with a vessel of her own size the majority of the casualties occur on the upper deck, owing to the lighter shells being more sensitive, and detonating immediately on impact (Fig. 67). Consequently, they do not create the same degree of de-

struction between decks, and the proportion of burns in the list of casualties is greatly diminished. The latter point will become evident by a study of the statistics set forth below.

The Destroyer.—These ships have gradually increased in size and power until the flotilla leaders resemble the small light cruiser in many respects. They may be rightly described as fast scouts. Their protection from enemy projectiles is almost negligible and, consequently,

FIG. 67.—ILLUSTRATING THE MEANING OF THE TERM "DÉBRIS" WHEN APPLIED TO A FIGHTING SHIP. FORECASTLE OF "EMDEN" LOOKING AFT, SHOWING WRECK OF FORE BRIDGE. CONNING TOWER BELOW WAS UNTOUCHED. (Courtesy of Surgeon Lt. G. D. Ferguson, R. N.)

no one position above the water-line is safer than another. The most important item in their construction is seen in the complete transverse bulkheads owing to the absence of any water-tight doors. Consequently, in order to pass from one compartment to another it is necessary to proceed by way of the upper deck. Most of the difficulties encountered in a light cruiser are intensified in a destroyer, such as the violent vibration and motion of the ship, with the result that little more than ampli-

fied first aid can be given to the wounded. The extremely narrow hatchways and almost vertical ladders render transport of the injured a

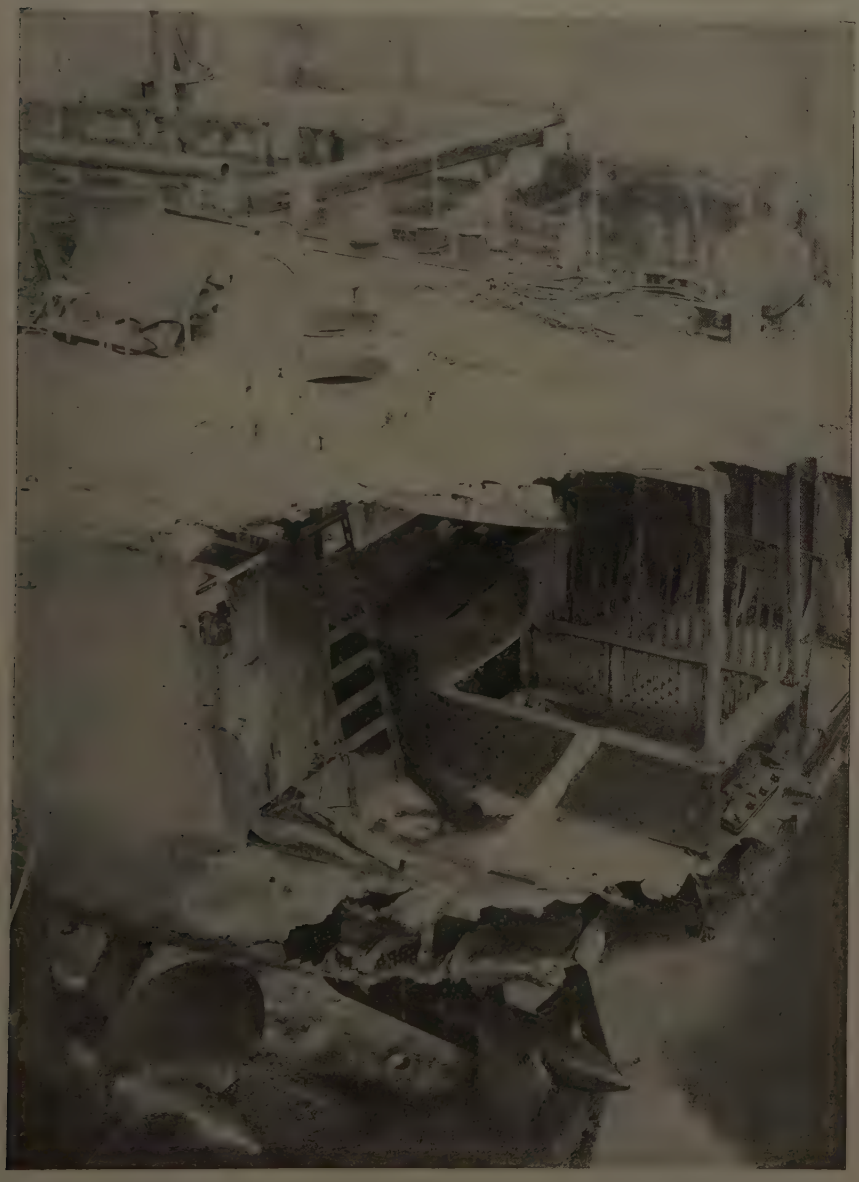

FIG. 68.—DESTROYER. HER STERN HAS BEEN BLOWN AWAY AND THUS A SECTION OF A SMALL FIGHTING SHIP IS SEEN. THE NARROW HATCHWAYS, VERTICAL LADDER, AND TRANSVERSE BULKHEAD ARE EVIDENT; THE VIBRATION FROM THE CLOSE PROXIMITY TO THE PROPELLERS CAN BE READILY IMAGINED. FROM THIS ILLUSTRATION THE DIFFICULTIES IN TRANSPORT AND TREATMENT OF THE WOUNDED AT SEA WILL BE OBVIOUS. (Courtesy of the British Admiralty)

hazardous proceeding owing to the use of stretchers being impracticable. This point is well illustrated in the accompanying photograph (Fig. 68).

Construction.—To whatever class of ship a medical officer is appointed, his first duty will be to acquire a thorough and detailed knowledge of her construction, without which he cannot be efficient. He should be quite conversant with the numbers and positions of the main bulkheads, the purpose of each compartment, which hatches are open and which are closed during action, the exact situation of the fresh-water tanks and the main ventilating trunks. His particular attention will be directed to the modes of ingress and exit from turrets, engine-rooms, stokeholds, and lower deck. By a close study of such details he will be able to estimate approximately where the majority of casualties are likely to occur and thus take the most desirable measures for dealing with them. This advice may well appear superfluous in times of peace; but the obliteration of spaces and the general after-effects of an explosion between decks will suffice to emphasize the fact that no detail in the construction is too small for the medical officer to leave out of consideration. Muir[2] illustrates this point well in describing the great difficulty experienced by a first-aid party in attempting to reach a wrecked compartment.

General Considerations.—The circumstances under which a warship meets the enemy vary to an extraordinary degree in the different types. The light cruiser and destroyer patrolling ahead are usually the first to obtain definite evidence of the position and course of the hostile ships. Consequently, the battleship, being forewarned, is forearmed. Again, a ship may leave her base equipped and prepared for immediate action or she may be continually at sea for months or even years always in readiness for the critical moment in her career which can never with certainty be foretold. Such considerations as these largely influence the medical organization, which is, therefore, adjusted to meet the needs of the hour. In any case, during war time, it is well to keep the sick bay free from cot cases as far as the exigencies of the service permit; a good working rule is to discharge to hospital or hospital ship at the first available opportunity any officer or man requiring the care of another person. Penfold[3] lays stress on this practical point and quotes a specific instance in which the arrangements for dressing the wounded were impeded from this neglect. Otherwise the efficiency of the ship as a fighting unit is impaired; the work of the surgeon is handicapped at the outset, and the meager accommodation in the medical distributing stations is encroached upon. "Pivotal" officers or men—*i. e.*, those who have been trained to carry out special duties peculiar to the ship—may be retained provided that they would be able to perform their allotted task in an emergency. Such problems will be solved by the common sense and skilful judgment of the surgeon.

On "action stations" being sounded off the medical parties proceed to their appointed place of duty without delay. The sick bay, in all probability, has been in use for the daily routine work; and the notes alluding to the sick are removed below together with the remaining instruments. The importance of guarding the reference books cannot be disregarded. Questions arise with regard to injury or previous ill-

ness, which can only be verified by the confirmatory evidence of these records.

Personal Equipment of the Surgeon.—Before proceeding to his station for action the surgeon will be well advised to assure himself that he is fully prepared to meet certain well-defined contingencies. The following list of essential accessories is recommended on the grounds of practical utility and expediency:

(1) A good electric torch (flash-light). It may be taken for granted that where casualties occur between decks the lighting in that section of the ship will have been temporarily destroyed. Without light the surgeon is helpless; he is unable to pick his way through the torn up decks or over a mass of wreckage or even render first aid to any wounded he may happen to find. The torch should be small enough to slip into the pocket when the surgeon is ascending or descending ladders.

(2) Wildey's hypodermic syringe and bottle. A good stout pattern of needle is advisable. If a large number of wounded require attention during a lull, rapid administration is essential; and breaking a needle at such a critical moment spells delay and discomfort. The morphin solution, preferably freshly prepared, is made in such strength that the maximum dose—*e. g.*, gr. $\frac{1}{2}$—fills half the 20-minim syringe; 20 minims is too large a quantity of fluid to be introduced hypodermically.

(3) A suitable respirator. This is carried loosely slung round the neck. It enables a surgeon to pass through a passage or compartment in which the atmosphere is fouled by fumes or smoke.

(4) India-rubber boots. After an action water seems to find its way to every deck and into each compartment. Owing to neglect of this precaution several medical officers worked for hours in salt water over their ankles. They sustained an edema of the legs somewhat analogous to the early stage of "trench foot."

(5) Two pairs of Spencer Wells forceps and a large pair of scissors.

(6) His assistant. If the services of one of the writer branch possessing a knowledge of shorthand can be secured they will prove invaluable. Penfold[3] attaches great importance to this factor. This assistant carries the tin or haversack containing the dressings, assists with the bandaging, and, if necessary, acts as a messenger. Maclean[4] and Holmes[16] call attention to the importance of writing or, better still, of dictating notes at the time.

The Surgeon's Difficulties.—Some of these have already been alluded to. They arise mainly from the fact that the conditions under which he works are almost the opposite to those which prevail ashore. Bereft of the assistance of the consultant or skilled anesthetist, he is faced with an almost herculean task. Critical observation may be precluded by the high pressure under which the work is carried on, while definitive treatment cannot be undertaken until the ship is outside the radius of further action. Maclean[4] and McCutcheon[5] both comment on the shortage of the trained staff which had been depleted by casualties in addition to the large number of wounded. Darby[6] refers to the delay in preparations from this cause, and also to the lack of conve-

niences. The sudden rush of cases requiring immediate attention is sufficient to tax the staff and accommodation of a well-equipped hospital ashore. Thus, the first two patients which Darby[6] saw were: 1, Fracture of the right leg with thirteen shell wounds; 2, penetrating wound of the chest with profuse hemorrhage. Muir[2] also points out the tremendous difficulties in dealing with large numbers of severely wounded men in a very short space of time. Penfold[3] saw half his medical stores and instruments destroyed by a shell explosion or the resulting fire and water, and this calamity severely handicapped the subsequent dressings. Any brittle gear is very liable to be broken by the concussion alone. Many medical officers have experienced a shortage of an adequate water-supply owing to damage to the supply pipes, and thus an accurate knowledge of the position of the fresh-water tanks is essential.

In spite of all these obstacles, each individual must add his quota to render the ship an *efficient fighting unit*, and to promote this primary object the surgeon is no exception to the rule. There must be, above all, whole-hearted co-operation with the executive and other branches, for unless complete harmony prevails the results will prove disastrous to all.

Protection of the Ears.—The noise during action compels some form of protection for the ears to be adopted. Mechanical contrivances, such as Elliott's, Ward Cousin's, and Mallock Armstrong's, serve this purpose. Cheatle's mixture of modeling clay and cotton wool is also satisfactory. On the other hand, the simplicity and efficiency of *cotton wool* or, better, *lamb's wool*, as Borrett[26] suggests, has everything to recommend it. Orders can be heard distinctly; it is comfortable to wear; and the tympanum is well protected from the violence of explosions.

During Action.—Speaking generally, there is little that can be done; in any case the incessant noise alone tends to limit the surgeon's activity. During this period, cooped in his distributing station, he waits in patience under circumstances which test his moral and physical courage to the full. Forbidden the excitement and interest inseparable from watching the effect of the enemy fire, and denied the active participation in the actual battle, his duty remains to instil confidence into his subordinates below. In no crisis is the need for discipline so stern as this. In the battle cruiser the thunderous blast of each salvo from the heavy guns reverberates throughout the ship; hardly has the crash of the first died away than a second takes its place. The bulkheads themselves shudder, shaking down their dust; the electric bulbs rattle in their sockets, and the very decks quiver under the strain. The severe effect of the concussion is felt especially in those medical distributing stations situated beneath turrets. The whole atmosphere is charged with an uproar impossible to describe. The boom of the salvos, the persistent scream of the enemy shells passing overhead, the sinister whine of the ricochets, the occasional shower of splinters on the resonant armor, the hurrying footsteps of the fire and repair parties above and the swirl of water create an extraordinary medley of sounds which seem wrapped in the muffled roar from the other

ships in the squadron. On a shell hitting the ship a dull thud is felt, followed instantly by a terrific explosion—then a moment of intense silence, during which she reels under the blow, rights herself, and proceeds. Under such circumstances her behavior is almost human. As a lull approaches the rhythmic vibrations of the turbines become more evident and gradually the normal familiar noises reappear. This must, of necessity, be only one instance when all goes well; there have been many occasions in which the engines have been put out of action for the time being, and such a catastrophe imposes an additional strain on those at their posts below the upper deck.

FIG. 69.—ENTRANCE OF A 12-INCH ARMOR-PIERCING SHELL. (Courtesy of Temporary Surgeon Lt. H. P. Margetts, R. N.)

From the brief description of a single experience it will be clear that any surgery or even first aid during the heat of a fierce action is not only undesirable, but absolutely impracticable. That humanitarian interests are best served by this mode of procedure is well shown by an incident which Muir[2] relates. During an action the latter received an urgent telephonic request for a medical officer and an ambulance party to proceed to a turret. This was refused on the ground that it was impossible to handle wounded men on stretchers through the working chambers, and to attempt to reach the turret by way of the upper deck would be an act of folly. The facts, which were subsequently ascertained, amply justified the refusal, since two men had been killed outright, and the wounded quickly found their own way down to the dress-

ing station. In all ships both officers and men should be educated by means of the first-aid lectures not to expect immediate attention by citing the case of the soldier who may remain hours or even days before his wounds can be dressed.

Armor-piercing Shells.—The effects of this type of high-explosive shell fitted with a delay action fuse will be understood by a study of the illustrations. Thus in Fig. 69 the entrance hole, just over 12 inches in diameter, appears to be almost punched out of the side of the boat deck; while Fig. 70 gives an excellent idea of the kind of damage produced by the resulting explosion. The steel decks and bulkheads are ripped and torn as if they had been constructed of tin foil. Consequently, there can be no estimate of the destruction once the projectile

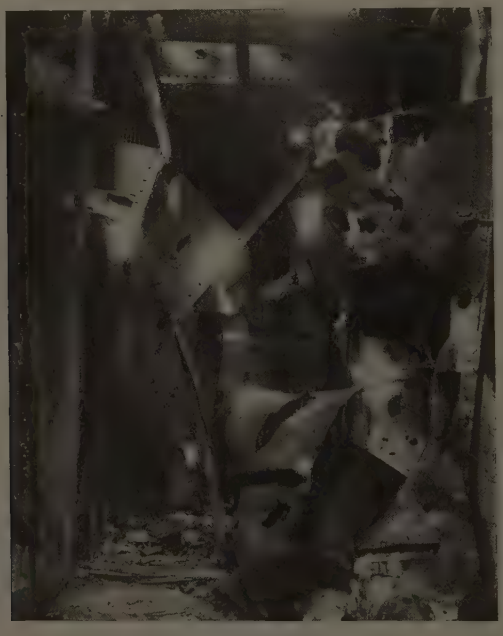

FIG. 70.—THE RESULT OF THE EXPLOSION OF A SHELL BETWEEN DECKS. (Courtesy of Temporary Surgeon Lt. H. P. Margetts, R. N.)

has passed through the protecting belt. The bulkheads tend to limit the area of havoc, but only after the shell has detonated. It will be remembered that the vast majority of the men are below the upper deck, and that the mess decks are congested with fire and repair parties. An explosion here creates utter confusion. The electric light in the section is cut off and absolute darkness reigns. The dead, dying, and wounded may be blown into an inextricable heap or perhaps scattered like chaff before the force of the blast. The fumes from the explosion and the smoke from the resulting fires add to the difficulties in reaching the scene. There is no doubt that many casualties would be saved if those men who are awaiting orders, including the medical parties, lay flat on the decks during action. In such a position they would be less

exposed to the flying fragments of shell and the flash of the explosion, thereby reducing considerably the high proportion of multiple injuries.

Occasionally, for reasons which are immaterial to us, the mechanism of the fuse fails to act at the critical moment or the projectile may not detonate at all. In one instance where the delay action proved sluggish the shell passed through fourteen bulkheads before its course was deflected upward by a beam. Finally it emerged through the upper deck, and exploded on the disengaged side, causing a little damage to the funnel. However, the mere passage of a shell possessing such tremendous velocity suffices to ignite any inflammable material within range. From this incident we are in a position to appreciate more

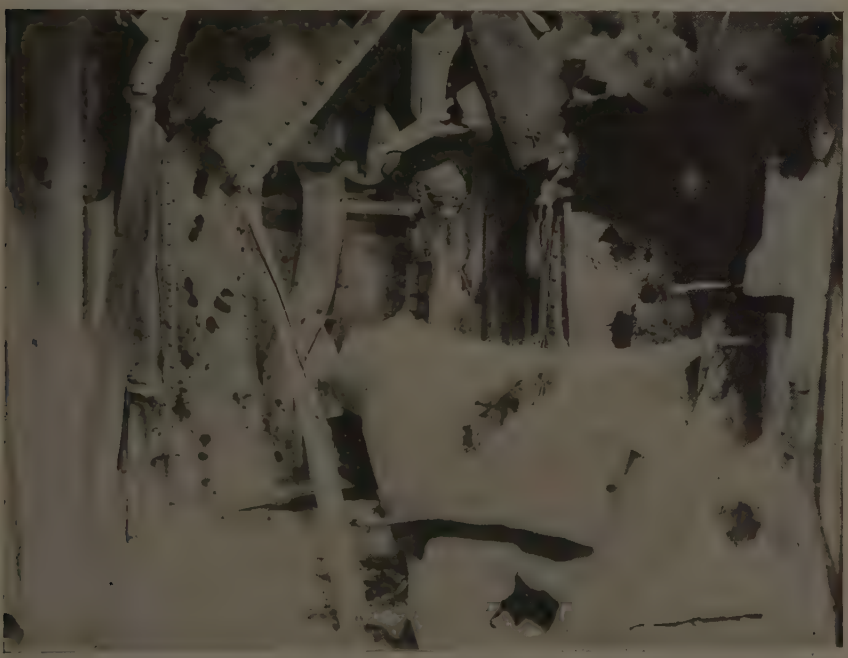

FIG. 71.—DESTRUCTION BETWEEN DECKS. THE LARGE NUMBER OF FRAGMENTS FROM ONE SHELL PIERCING THE BULKHEADS ILLUSTRATES THE LIABILITY TO MULTIPLE WOUNDS. NOTE DAMAGE TO ELECTRICAL WIRING. (Courtesy of the British Admiralty.)

fully how our lines of communication for transporting the wounded may be cut; how telephone and electric systems may be rendered useless, and how water-supplies to the medical distributing stations may be interfered with (Figs. 71, 72, 73).

Effect of Shells Bursting on the Upper Deck.—In the larger ships turrets give considerable protection to those who man the heavy guns. In light cruisers, however, only thin plating screens the gun's crew from splinters. The bridge and superstructure afford the only available cover for those on duty there. Figure 63 depicts the damage wrought on the upper deck of the Emden, and the difficulty of rescuing the wounded buried under such débris is manifest. Should a projectile penetrate

FIG. 72.—ILLUSTRATING THE LARGE IRREGULAR NATURE OF THE FRAGMENTS AND THE MOMENTUM WHICH THEY MUST HAVE POSSESSED TO PIERCE STEEL PLATING. (Courtesy of the British Admiralty.)

FIG. 73.—ANOTHER EXAMPLE OF THE TERM "DÉBRIS." THAT TORN AND CRUMPLED STEEL PILING IS WELL SHOWN. (Courtesy of the British Admiralty.)

the armor of a turret and detonate within, all are killed or mortally wounded. On the other hand, it may only strike a glancing blow, as in one instance where the roof was dented; even then some of the men inside may be killed or severely concussed. Fragments of shell possess a wide "spread," which contrast with conditions between decks where

FIG. 74.—STERN OF A TORPEDOED HOSPITAL SHIP. (Courtesy of the British Admiralty.)

the bulkheads limit the area of destruction when once the shell has exploded.

Torpedo Hits.—The implosions produced by weapons such as the torpedo and mine invariably create severe damage to the ship herself. In destroyers almost everyone suffers to a slight extent from shock, but this is not sufficient to prevent men from carrying out their duties.

Those in the vicinity are frequently affected by the resulting fumes. The latter, together with the inrushing water, form the chief obstacles in repairing the damage and rescuing the wounded (Figs. 74, 75).

Flash from Explosions.—When a shell detonates between decks the resultant flash, spreading through the compartment, produces superficial burns on the exposed parts of the body, chiefly the face and hands. In a few instances the flame has run up the trouser leg and scorched the skin above the boot. Bunton[8] mentions an interesting case of an officer whose penis was severely burnt owing to the flash passing through the fly button opening. Men possessing a different means of access

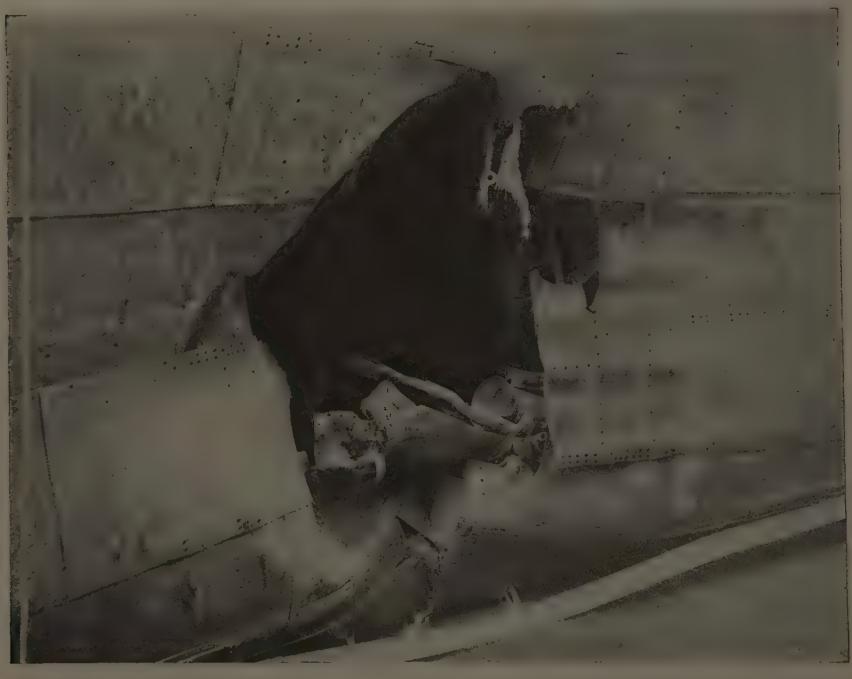

FIG. 75.—A TORPEDOED MERCHANTMAN. THE EFFECT OF THE EXPLOSION IS ILLUSTRATED BY THE CRUMPLING OF THE STEEL PLATES INWARD, ALL THE RIVETS IN THE VICINITY BEING SHEARED. (Courtesy of the British Admiralty.)

in this locality are thus immune from such disaster. Bunton[8] also refers to superficial burns of the cornea being frequently observed, but this is uncommon. In the great majority of cases the eyes escape injury in spite of the eyelids being burned, owing to the reflex action exerting its protective power. A large number of those who were wounded between decks suffered from this type of injury in addition, and this was an important factor in increasing shock. Penfold[3] experienced a flash from an explosion on the upper deck passing down the ventilating trunk and burning men in the vicinity of the delivery opening below.

The methods of preventing such burns will no doubt prove effective. Men below awaiting orders, such as fire and repair parties, will lie on the

deck instead of standing up; and they will be equipped with a helmet of thin, non-inflammable material and gauntlets. The trousers may be tucked into the stockings as an additional precaution.

Fires in the Ship.—These are not of great consequence in adding to the list of casualties, but they greatly impede the medical arrangements below. Fumes and smoke are alluded to elsewhere, but the chief inconvenience is caused by the water flooding the passages and decks, where the wounded are accommodated.

Scalds.—In the table of statistics scalds have been included among "burns, slight." No case died from this cause. Only six were noted, but it should not be forgotten that they may become a large proportion in the list of casualties. The light cruiser and destroyer are more liable to suffer in this respect owing to the steam pipes being nearer the water-line and thus coming within range of the shell splinters.

"Rope burns" deserve to be noticed in order to remind medical officers of one form of injury to expect should his ship be engaged in rescuing survivors. Hingston[7] describes how over 200 cases of third degree burns of the palms of the hands were produced by sliding down a rope. The inner aspect of the thighs were not affected to the same extent, owing to the protection afforded by the trousers.

Cordite Fires.—These are produced by the ignition of packages of cordite during their transfer from the magazine to the breech. They are responsible for the most severe and fatal type of burn. Cordite burns fiercely, and the resulting wave of flame darts along passages, up and down hatches, following the path of least resistance in a most singular manner. To illustrate this important point one example may be quoted, since the large number of killed is not infrequently due to this causal factor.

A turret was penetrated by a heavy shell which detonated within, killing or mortally wounding all the members of the guns' crew, in addition to blowing off the front roof plate. Almost a quarter of an hour afterward fire from some smoldering clothing reached the cordite charge in readiness for loading, and set this alight. The flash from this secondary explosion found vent partly through the open roof, but the flame also shot down the trunk, where it ignited more cordite which was awaiting delivery. This sheet of fire fled by another route past the shell rooms, upward to the switchboard flat, up a hatchway on to the port side of the mess deck, whence it proceeded forward, then across to the starboard side, and finally burnt itself out going aft. The heat generated by this wave of flame may be gaged from the fact that both glass and steel were melted in its path. All the occupants of the passages were killed; and these included the whole of the after first-aid party with the surgeon in charge. The position for the latter had been selected as being immune from the effect of a shell explosion since its situation was 20 feet below the water-line. The dead were discovered lying precisely at their action stations; in some cases they had been jammed together and wedged into a narrow alleyway by the force of the blast so that they appeared to be standing up—lifelike. Their

appearance was similar to waxen figures of a deep yellow hue, their unaltered features testifying to the instantaneous onset of death. At one point where the flame had paused for a moment, prior to rushing up a hatch, the flesh was charred and blackened as burns of the third and fourth degree. In 3 cases the scalp had been completely burnt away, leaving the polished vertex of the skull bare. One man was discovered alive ten minutes after the event, but he died before assistance could be rendered. The reaction of this erethitic shock was so tremendous that even in such a short space of time his features could not be recognized owing to the edema. To what extent this was due to the terrific heat, the pressure of the blast, or the irritant chemical must be left to conjecture.

Fumes and Smoke.—In view of the important part which poisonous gases and lacrimatory shells played in the battles ashore, precautions had to be taken to meet this contingency afloat. On the upper deck little or no material damage could be effected by this means owing to the speed of the ship; but the consequences of an irritant gas fouling the air between decks would be terrible to contemplate. From the technical standpoint an ounce of bromin or liquid chlorin in a glass ampule would not materially impair the bursting charge of a heavy armor-piercing projectile. However, there is no definite evidence that such a method of fighting was employed at sea.

On the other hand, noxious fumes arise from many other causes which may add to the casualties and always impede the working parties, thus diminishing the fighting efficiency of the ship. The fumes resulting from an explosion defy an accurate analysis since they immediately commingle with smoke from burning débris, clothing, hair, and paint. Probably the oxids of nitrogen predominate with carbon dioxid; in some cases certainly carbon monoxid has been present. During practice with subcaliber tubes fitted in the larger guns the air blast to clear the chamber cannot be employed; under such conditions men working near the breech occasionally fall unconscious with symptoms of carbon monoxid poisoning. They recover slowly on exposure to the open air and stimulants.

The gases derived from explosives in a ship have been well described by Fairlie,[25] and the following paragraph is quoted from his paper: "The cordite at present in use is known as 'Cordite M. D.,' and is composed of guncotton 65 per cent., nitroglycerin 30 per cent., and mineral jelly 5 per cent. The ignition point is 180° C., but ignition is not readily caused by small flames. However, cordite, once ignited, is put out with difficulty. It is kept in rods, which, if ignited in air, burn with a yellow flame. When blown out they continue to burn, but without a flame, giving off thick fumes. The gases produced by the complete detonation of cordite do not, as a rule, cause poisoning according to Leonard Hill.[9] The late Professor Vivian Lewes calculated that a 15-inch gun with its charge of 400 pounds of cordite gives off 2500 cubic feet of carbon monoxid. This rapidly diffuses through the atmosphere and no poisoning results, even though 1 per cent. of carbon

monoxid rapidly produces unconsciousness. When detonation is *incomplete*, nitrous gases as well as carbon monoxid are produced, the amount of each varying with the available supply of air. In a confined space the amount of carbon monoxid may be considerably increased. The more imperfect the combustion, the greater also will be the amount of nitrous gases produced."

Nitrous gases consist of a mixture of the oxids of nitrogen, most of which are unstable and rapidly change from one to the other. Colorless nitric oxid is probably formed first. This is rapidly oxidized to nitrogen peroxid, which is reddish brown in color, and in the presence of moisture changes into nitrous acid. When inhalation takes place the deadly effects are due to the action of nitrous and nitric acids. The fumes smell like fuming nitric acid, the pungent and irritating properties being readily recognized even in small quantities. The symptoms produced by inhalation are those of a respiratory irritant very similar to the group of gases which includes chlorin and bromin.

That these nitrous fumes even in small amounts produce serious results is shown by the fact that the air of mines after blasting with nitroglycerin explosives contains such a minute percentage of these gases that until recent years they were not considered to play any part in the deaths that they undoubtedly caused. As small a quantity as 1 per cent. renders an atmosphere irrespirable. It is probable, however, that infinitesimal amounts, if inhaled for a short time, will produce serious results.[11] "Exposure to as little as 0.05 per cent. nitric oxid for half an hour was found by Haldane to cause death in mice after twenty-four hours with the typical sequence of symptoms."[10]

Of the 11 cases mentioned in the statistics of the battle of Jutland, 3 proved fatal. Two were undoubtedly due to nitrous fumes; the other, in which death occurred very rapidly, was probably caused by a combination of gases including carbon monoxid. Generally speaking, the predominating oxids of nitrogen give rise to the train of symptoms described below, which is based on Fairlie's observations in cases from a ship that was torpedoed; a magazine explosion followed: 130 casualties occurred, of which 39 were killed outright or died before reaching hospital. Of the 91 cases admitted, 56 suffered from gas-poisoning; 10 of the latter died. All suffered from the effects of inhalation of nitrous fumes and this was probably the cause of death in many others. The author suggests that many who were lost in the ship, if not killed outright, may have been rapidly overcome by gases, including carbon monoxid.

Duration of Exposure.—The period of exposure that will afterward give rise to symptoms varies with the percentage of nitrous gases present. The more prolonged the exposure and the greater the amount of these gases present, the more rapid and more serious are the results likely to be. On the other hand, it should be remembered that very short exposures may produce serious results, as is shown by the following cases, *both* of which proved *fatal:*

L. G. W. After coming up from the starboard engine-room subsequent to the explosion, in order to start a fire main, he attempted to go below again, but was unable to proceed owing to the irritant nature of the fumes.

J. A. S. After coming on deck he attempted to go below again to close a door, but had to turn back at once, as he could not stand the fumes.

Initial Symptoms.—At the time of exposure there may be only a slight feeling of irritation in the nose and throat; but this may be accompanied by headache and a sense of constriction in the chest. Hewitt,[12] who suffered himself, refers to the sickly stupefying sensation associated with nausea and dizziness which he experienced shortly after inhalation. The immediate symptoms are, almost invariably, slight and quickly pass off.

Latent Period.—When poisoning is due to nitrous fumes entirely there is usually a latent period between the exposure and the onset of serious symptoms, which varies from an hour to twenty-nine hours. In Fairlie's series all those which occurred within five hours proved fatal and died within that time. The remainder varied between five and twenty-nine hours. Symons,[13] who received 17 cases from a ship which sank after striking a mine, states that the latent period varied from four and a half to seventeen hours, during which the men were remarkably fit. There are no grounds for believing that there is any definite relation between the duration of the latent period and the severity of the symptoms. Serious cases may have a long latent period and, conversely, slight cases a short one. Absence of any disturbance is the salient feature after the initial symptoms have passed off. Men from one ship were landed at noon, marched to their quarters, and there carried on their duties until the evening, when the serious symptoms developed.

Symptoms.—(1) *Stage of Irritation and Spasm.*—The onset is frequently abrupt, being ushered in with shortness of breath and a feeling of constriction and pain across the front of the chest. The expression becomes alert and somewhat anxious, with pallor of the face, and a bluish tinge on the lips and lobules of the ears. An irritating dry cough develops and perhaps vomiting may occur. The latter affords considerable relief. Examination of the chest reveals no abnormal physical signs save a slight harshness of the respiratory murmur. This stage may pass off and all symptoms abate in twenty-four hours.

Should the attack continue, the cough and pain increase in severity; dyspnea becomes marked; the respirations remarkably rapid, reaching 60 per minute in Fairlie's cases and 96 in one observed by Symons; the patient himself is restless and cyanosed. Auscultation shows numerous rhonchi scattered throughout both chests and a few medium crepitations at both bases. Resolution may take place and recovery be almost complete in twenty-four hours; but the crepitations are audible for two or three days afterward.

(2) *Stage of Acute Pulmonary Congestion and Edema.*—The commencement of this stage is characterized by the appearance of frothy sputum, marked cyanosis, and shallow, rapid respirations. Cardiac embarrassment is evident from the accentuated second sound in the pulmonary area. Restlessness is distressing, the patient jumping about the bed in his struggle for breath. Physical signs demonstrate the presence of a grunting expiratory murmur with fine and medium râles all over the lungs, but especially marked at the bases behind.

Later, symptoms advance with alarming rapidity. The sputum, now mixed with blood, pours from the mouth and nose. The skin is cold and clammy, wearing a dusky slate hue. Complete consciousness prevails and the patient groans aloud for relief from his agony. The bubbling râles in his chest do not require a stethoscope. Signs of recovery are noticed in the amount of sputum becoming less and cyanosis subsiding. Of 20 cases which reached this stage, 10 died.

In 4 death occurred during the period of profuse secretion; in 5 death ensued from cardiac muscle failure in the latter stage. Only in 1 case was death sudden. Bunton's[8] cases passed into a state of coma before death, but Symons[13] remarks on its absence as being noteworthy. Such differences must always exist, since the details in symptoms will vary according to the amount and percentage of the number of gases inhaled.

The problem of neutralizing the effects of poisonous gases may be considered under two headings:

(1) Respirators. (2) Ventilation.

(1) A respirator which will meet every possible contingency on board a fighting ship has yet to be devised. Cumbersome tubes and such like contrivances are a source of hindrance to the wearers, and thus at once defeat their own object, viz., to enable orders to be carried out efficiently. A model mask should be simple, easily adaptable, and an adequate safeguard against smoke and fumes. We employed an oblong pad of cotton waste impregnated with an alkaline solution of sodium hyposulphite. This was enveloped in a thin layer of black gauze and kept moist by means of a little glycerin and water. It should be noted that, after being in use for a quarter of an hour this pattern becomes dry and requires damping to improve its power of absorption. In practice, as Maclean[4] and Muir[14] bear witness, these simple respirators served their purpose admirably, and there can be no doubt of their efficacy in neutralizing the deadly effects of acid fumes. On the other hand, an atmosphere polluted by ammonia or carbon monoxid would disqualify them for universal use. Lorrain Smith suggested freshly prepared charcoal as a suitable material, and our experiments proved that this substance used as a respiratory channel possesses remarkable power in absorbing poisonous gases from fouled air. However, its bulk and the practical difficulty in obtaining it in the freshly prepared state stood in the way of this scientific fact being technically applied.

(2) The substitution of artificial for natural ventilation in the warships of today proceeds apace. The wind-screen and cowl have long been obsolete, and now even the scuttle is doomed. Compartments below are supplied with fresh air from the upper deck, which is drawn down the ventilating shafts by powerful electric fans; and the foul air is removed by a reverse process. A mushroom top protects the upper end of the shaft from the advent of water. Bearing these fundamental facts in mind, it will be readily admitted that the problem of sufficient ventilation of spaces between decks, even in the absence of noxious fumes, is liable to become acute during action. Smoke and dust may be brought down from the upper deck to foul the compartments below; the driving power of the fans may be damaged; or the shaft itself may be wrecked by fire or explosion. In one case a supply fan was transformed into an exhaust by the vagaries of a shell fragment. During action the exhaust fans run at full bore; but there is some difference of opinion with regard to using the supply. Many switched off these at the commencement and restarted them during a lull. Muir,[14] however, strongly advocates keeping the supply fans running throughout, as the chances of fumes being brought down from above are negligible. As he rightly points out, should the air of a compartment be fouled the fumes would be rapidly diluted by the supply. On the other hand, it is a simple matter to switch on any fan when required. The balance of opinion leans toward keeping the supply fans working continuously during action; but if this scheme is followed, then the delivery openings of the ventilating shafts must be guarded with wood shavings impregnated with an alkaline solution of sodium hyposulphite.

Treatment.—Prophylactic measures, if thoroughly carried into effect, will reduce the number of casualties from gassing to a very large extent. By means of first-aid lectures the men should be educated to appreciate the danger of inhaling fumes after an explosion of any kind has occurred; to accustom themselves to wearing the pattern of service respirator which provides ample protection from nitrous gases, to report themselves at the sick bay even if the period of exposure has been short or even momentary.

After an explosion has taken place the whole area involved will automatically become out of bounds to everyone unless masked. "On masks" will be the order of the future to all working in the vicinity of the fumes. The delay in the onset of serious symptoms by reason of the latent period should be explained in order to impress the necessity for being kept under observation for forty-eight hours. During this time the diet and alcohol will be curtailed.

At the earliest moment when the symptoms arise an attempt is made to check the formation of secretion. Atropin (gr. $\frac{1}{150}$ to $\frac{1}{100}$) may be administered hypodermically every three hours with advantage. If, however, secretion is profuse this drug is contraindicated, since it tends to render the sputum viscid and difficult to expectorate.

Emetics are of pronounced value in the early stages. The vomiting induced by 30 grains of zinc sulphate relieves the spasm and, in addition, greatly hastens the expulsion of the frothy sputum. Considerable relief is afforded to the patient by this procedure.

Ammonia in the form of ammonium carbonate (gr. 5) four hourly is beneficial, and should be continued until the lungs are quite clear.

Contrary to expectation, oxygen is of little avail. In the most acute stage, when its effect would prove of inestimable value, the writhings of the patient coupled with the copious exudate flowing from the mouth and nose present insuperable obstacles to administration. Even in the later stages when the secretion is less the results are very disappointing, although the oxygen-carrying power of the blood is so diminished by the formation of methemoglobin. The posture of the patient is important, the most suitable position being on the side with the head hanging over the side of the bed, which should be raised at the foot.

Bleeding.—Most striking results are derived from venesection and many severe cases have been saved thereby. The earlier this is practised after the onset of serious symptoms, the better will be the results. Owing to the thickness and viscosity of the blood, excision of a portion of the median basilic or median cephalic veins is the operation of choice. The patient may require several bleedings to obtain the required result. The maximum benefit is attained by removing 12 ounces. Immediate relief is given and both the cyanosis and dyspnea abate.

The intravenous injection of saline did not alleviate the symptoms to any appreciable extent. Strychnin or ether hypodermically give a little stimulating effect in the latest stage, but they cannot be relied upon when the pulmonary edema prevails.

Fairlie[18] alludes to acute pulmonary emphysema, cardiac irregularity, indigestion, and relapse during convalescence. The latter is rare in naval cases, only one being noted. On the other hand, Withaus[15] quotes a series of cases collected by Hall and Cooper in which relapse occurred in one-third and averaged fifteen days in duration.

Acute pulmonary emphysema comes on with rapidity and may be diagnosed shortly after the secretion has abated. This complication was present in 16 cases, and the degree varied with the severity of the symptoms. Physical signs showed a hyperresonant note over the whole of both lungs, with diminution or obliteration of the cardiac dulness. The normal size of the lungs reappears with a normal frequency of respirations in two to four weeks.

Immediately After Action.—This period will impose a heavy task on the medical organization should a large number of casualties occur. For the surgeon the most critical moment at which "his services cannot be spared" has arrived; and it behooves him to appreciate fully the nature and relative importance of the demands which he is called upon to meet. After relieving pain and controlling hemorrhage his first duty remains to restore order out of chaos where the wounded lie. On reaching the damaged area, whether this be situated on the upper deck or between decks, he will palliate the most severely wounded first; but there is little time to pick and choose. Each patient receives a dose of morphin and is forthwith labeled with the quantity given and the time of administration. This drug acts like a charm in stilling the cries of the wounded. Any copious hemorrhage is checked by plugging, the application of Spencer Wells forceps or a tourniquet, according to circumstances. By such means alone can discipline be re-established. The wounded and dying, having been sorted from the mass of wreckage and the dead—a most difficult and exacting task—are placed

under cover as near as possible where they fell. In light cruisers where the majority of casualties occur on the upper deck they must be removed below to shield them from cold and exposure. In destroyers the mess deck below the forecastle offers the most suitable and accessible accommodation.

The surgeon's next care will be to supervise the application of temporary dressings in order to mitigate the degree of infection. It cannot be expected that covering a recent wound with cyanid gauze or a burn with picric acid will eradicate the primary foci of infection; but it serves the valuable purpose of protecting the area from the addition of further infection. Spraying the wound and surrounding skin with iodin prior to applying the first-aid dressing is excellent practice.

Morphin.—Experiences in action have given additional strength to the reliance which we had hitherto placed in the valuable properties of this drug. It is universally acknowledged that no other single article in the surgeon's equipment is so indispensable. Undoubtedly, the hypodermic method of administration is to be preferred, since the rapidity of action and accuracy of dosage are thereby ensured. Tablets placed under the tongue or drafts given by the mouth may be considered as clumsy alternatives and, as such, are not recommended. It should not be forgotten that the alkaloid itself, whether in solution or tablet form, deteriorates on exposure to light and warmth, so that the amount given should depend on the effect produced. Men who have sustained injuries a few minutes previously bear full doses of morphin admirably. If the drug is administered boldly the degree of primary wound shock and hemorrhage will be strikingly reduced.

Brandy given by the mouth in addition is good practice. Thirst is relieved and the effect of the morphin enhanced. No confidence can be placed in alcohol as a cardiac stimulant; but the sedative effect on the cerebral centers serves a useful purpose. Thus it will be seen how the combination of these two drugs materially assists in cutting off the painful afferent stimuli from the medullary centers which facilitates subsequent transport. Hyoscin hydrobromid may be mentioned here as being a useful means of allaying the restlessness associated with those who have received cranial injuries.

Hemorrhage.—On the whole, primary hemorrhage has been less than was anticipated, owing to the high temperature of the shell fragments searing the tissues. In some instances it was, of course, terrific, and the men died before assistance could be rendered. Hopkins[19] refers to great difficulty which he experienced in controlling oozing of blood from deep wounds in a destroyer which was within the radius of action.

First Aid.—It is unnecessary as well as impracticable for the whole ship's company to be trained in this subject. Much labor and time may be expended in attempting to do this, with most disappointing results. Maclean[4] and Muir[14] both clearly indicate that no reliance can be placed on the men as a whole for this purpose. The vast majority are terrified, and not without reason, at the sight of their mutilated

comrades; instinctively they shrink from touching their wounds, and invariably seek assistance from the trained staff.

On the other hand, the necessity for a certain proportion of men—*e. g.*, 20 per cent. of the complement—to undergo a thorough course of instruction cannot be denied. With these it is good practice to demonstrate in the sick bay how small wounds are dressed, so that they may become accustomed to the sight of blood, and "case-hardened" in the presence of pain and suffering. War conditions have proved conclusively that first aid should form an integral part of every naval officer's curriculum.

Wound Shock.—The degree of shock which the wounded display depends on many factors or, rather, combination of factors, chief among which may be mentioned multiple injuries, fractures, burns, hemorrhage, and rough handling during transportation; but the condition should not be looked upon as inevitable, since valuable preventive measures may be undertaken to minimize its extent. Generally speaking, the temperament of the sailor is such that he bears the shock of severe wounds admirably. It has been frequently asserted that the excitement of action stands him in good stead, but for those on duty below the upper deck this tendency can readily be overestimated. On the other hand, the knowledge of victory exerts a very definite influence in overcoming shock.

Preventive treatment to be successful must be immediate, and therefore the time which has elapsed between the infliction of the injury and the arrival of the surgeon deserves the utmost consideration. This period may vary from one or two minutes to half an hour; on an average the wounded receive attention within a quarter of an hour. Local shock is generally pronounced; and this phenomenon should not be neglected in the rapid applications of first-aid dressings. These reflections will emphasize the great need for close co-operation between the captain of the ship and the senior medical officer. Since every moment is of the greatest import, the latter should be informed at the earliest opportunity of any likelihood of a lull.

Prophylaxis of wound shock in a fighting ship can be summarized in rest and warmth. With these two fundamental points in view the wounded man is placed in the nearest cabin or compartment, so that his presence does not hamper the activities of those who are left to carry on. In the first place, then, he should not be moved more than is absolutely essential to secure this end. Men take a considerable time to recover from the initial shock; if transported or roughly handled during this period the negative phase of this condition is markedly accentuated. Adequate ventilation is also most desirable, but cannot always be obtained. In destroyers the patients may with advantage be accommodated on the engine-room or stokehold gratings for the sake of the extra warmth. Afterward they can be transferred to the mess deck forward.

Transport.—In a previous paragraph the advisability for not moving the wounded more than is necessary has been emphasized; and this

will become even more apparent after the facilities for transport have been considered. The advantages and disadvantages of the different methods employed may now be discussed:

(*a*) *Man-handling.*—Probably no form of mechanical contrivance has proved equal to this for general utility. In light cruisers and destroyers where sharp angles and limitations of space impede the use of stretchers it is frequently required. Regular practice is essential; and if this is supervised by the medical officer so that the bearers realize the necessity for the utmost care in handling fractured limbs excellent results will follow. Wounded are often discovered in positions which absolutely prohibit the manipulation of any form of stretcher, and then this method becomes imperative.

(*b*) *Neil Robertson Stretcher.*—The details of this type have already been described in Vol. VI, p. 779, and there is no need to reiterate them. In the larger ships we have found that it fulfilled all reasonable demands. When carefully applied the comfort of the patient even with fractured limbs is remarkable. For light cruisers and destroyers its use is more restricted for the reasons given above. Yet Holmes[16] and Darby[6] both considered it very efficient for carrying wounded between decks and up and down ammunition hoists. Hingston[7] has drawn attention to the buoyancy of this appliance—a very admirable quality for any fitting in a ship to possess. He relates how a compound fracture of the tibia and fibula had been put up temporarily in it when the ship was torpedoed. Ultimately the patient found himself immersed. He was shortly afterward discovered floating with his head and shoulders out of the water. He was then secured to a raft, rescued, and subsequently restored to health.

(*c*) *Bamboo Stretchers.*—These consist of two bamboo poles kept apart by steel stays. The intervening canvas is fitted with shoulder-straps and a perineal band. This pattern serves the same purpose as the Neil Robertson, but it is especially useful in light cruisers where the tier system of accommodating the wounded is practised. By slipping the ends of the poles into loops on wire slings suspended from the deck above they are converted into cots.

Stokeholds and engine-rooms have always presented many difficulties in the satisfactory removal of injured to the dressing stations. Now that an air-lock is fitted to the smaller vessels the obstacle becomes almost insuperable. Stretchers are out of the question and man-handling is the only alternative. If the men cannot be got up without grave risk, then the duty of the surgeon remains to follow the principle of Mahomet and go down to render the desired assistance in the stokehold itself.

(*d*) *Canvas Chutes.*—Holmes[16] strongly recommends these as being an excellent means of transporting the wounded from the upper deck to the deck below through the narrow hatchways and down the steep ladders so characteristic of light cruisers; and the details appended are based on his description. A wide strip of canvas is attached at one end to a spar. The latter is lashed to the stanchions on either side of

the coaming of the hatch, and the canvas thus falls down loosely, covering the steps of the ladder. Men on the deck below now hold the canvas out taut with the aid of two lanyards rove into its lower free border. During a night action this device worked splendidly. The wounded were man-handled to the top of the ladder, placed on the stretched out canvas, and thus slid gently down to the deck below. They reached the dressing station within five minutes of the commencement of the lull. For those patients who could walk down the canvas was simply rolled to one side.

Notes on the Statistics.—The table on p. 275 has been compiled from Admiralty returns by Surgeon Commander W. L. Martin, R. N., whose remarks form the basis of this paragraph. All the British ships which sustained casualties in the battle off the Jutland coast on May 31, 1916 are represented and have been arranged in order according to the classification adopted in the early part of this chapter. Inferences from a study of these figures must be drawn with extreme caution, since the action was not completed and the main squadrons of battleships had not engaged each other. Nevertheless, the list may be accepted as an example of the probable trend of events in a modern naval action in which a fleet is compelled to accept battle within a hundred miles of its principal base.

Killed Outright.—Although many of the killed had received both shell wounds and burns, it is estimated that the primary cause of death in 343 was shell wounds and in 114 burns, while in 4 no trace of any injury was discovered. The remainder of the deaths, *i. e.*, 5653, shown in the first column, are presumed to have been drowned. In all probability the vast majority were killed instantaneously by the secondary effects of the enemy gun-fire, such as a magazine explosion, in which a ship and her entire complement are utterly destroyed in a moment. Individual ships varied greatly in the numbers killed by shell wounds and burns respectively. Thus in the "Barham," "Princess Royal," and "Tiger" all the deaths—22, 19, and 20 respectively—were due to shell wounds; in the "Malaya" all (33) were caused by burns; while in the "Lion" 48 of the killed had combined wounds and burns, 49 had shell wounds only, and 2 burns only. The reader is again reminded to accept these details with reserve. In a ship which has sustained a heavy list of casualties the whole attention of the medical staff is claimed by the wounded, and the requisite scientific examination of the dead to determine the precise cause of death cannot be expected.

Wounds.—These will be described in detail subsequently. Columns 3, 4, and 5 form an arbitrary but useful guide to the naval surgeon. Such figures will demonstrate the great variations in the proportion of different injuries received by ships of the same class under identical circumstances; it is also quite evident from the tables how much more prone the larger ships are to suffer from burn casualties in comparison with the light cruiser and destroyer.

The regional nature of compound fractures will be understood from the following list, which includes those that died from wounds as well

BATTLE OF JUTLAND

Killed and Wounded

Ship.	Killed outright or drowned.	Died of wounds.	Wounded.		Burnt.		Combined injuries, wounded and burnt.		Gas poisoning.		Total wounded.	Total casualties.	Complement on May 31, 1916.	Total wounded per cent. of complement.
			Severe.	Slight.	Severe.	Slight.	Severe.	Slight.	Died.	Recovered.				
Barham	22	4	4	9	19	8	..	2	..	..	46	68	1124	4.09
Colossus	....	..	2	6	..	..	..	1	..	..	9	9	....	.....
Marlborough	2	..	..	2	..	..	..	..	..	..	2	4	....	.....
Malaya	33	32	1	4	7	23	..	..	..	1	68	101	1032	6.58
Valiant	....	..	1	..	..	..	..	..	..	..	1	1	....	.....
Warspite	9	5	4	15	5	3	..	..	..	..	32	41	1048	3.05
Lion	95	5	9	11	3	13	7	3	..	..	51	146	1229	4.14
Princess Royal	19	3	8	6	6	52	6	..	..	..	81	100	1202	6.73
Tiger	20	2	5	8	8	9	5	1	3	5	46	66	1281	3.59
Queen Mary	1258	1	1	4	..	..	..	..	..	..	6	1264	....	.....
Invincible	1026	..	..	1	..	..	..	..	..	..	1	1027	....	.....
Indefatigable	1017	..	..	..	..	..	..	..	..	..	..	1017	....	.....
Defence	902	..	..	..	..	..	..	..	..	..	..	902	....	.....
Warrior	65	3	9	19	1	2	..	..	..	2	36	101	832	4.32
Black Prince	856	..	..	..	..	..	..	..	..	..	..	856	....	.....
Calliope	7	3	9	17	..	..	..	..	..	..	29	36	....	.....
Caroline	2	..	..	..	..	..	..	..	..	..	..	2	....	.....
Castor	12	1	9	16	..	..	..	..	..	..	26	38	....	.....
Chester	29	6	8	22	3	7	2	1	..	..	49	78	424	11.55
Dublin	3	..	6	21	..	..	..	..	..	..	27	30	460	5.86
Southampton	29	5	15	30	4	1	2	3	..	..	60	89	498	12.04
Broke	47	..	9	23	..	4	..	..	..	..	36	83	200	18
Tipperary	184	..	2	2	..	..	..	..	..	..	4	188	....	.....
Ayanta	6	..	1	..	..	..	..	..	..	..	1	7	....	.....
Ardent	78	..	1	..	..	..	..	..	..	..	1	79	....	.....
Defender	1	..	..	2	..	..	..	..	..	..	2	3	....	.....
Fortune	67	..	1	1	..	..	..	..	..	..	2	69	....	.....
Moorsom	....	..	..	1	..	..	..	..	..	..	1	1	....	.....
Nessus	7	..	5	2	..	..	..	..	..	..	7	14	....	.....
Nestor	6	1	7	..	..	..	..	..	..	..	8	14	....	.....
Nomad	8	..	3	1	..	..	..	..	..	..	4	12	....	.....
Obdurate	1	..	1	..	..	..	..	..	..	..	1	2	....	.....
Onslaught	5	..	3	..	..	..	..	..	..	..	3	8	....	.....
Onslow	2	1	..	2	..	..	..	..	..	..	3	5	....	.....
Petard	9	..	3	3	..	..	..	..	..	..	6	15	....	.....
Sparrowhawk	6	..	..	..	..	..	..	..	..	..	..	6	....	.....
Spitfire	5	1	5	13	..	..	1	..	..	..	20	25	....	.....
Shark	85	1	1	1	..	..	..	..	..	..	3	88	....	.....
Porpoise	2	..	1	1	..	..	..	..	..	..	2	4	....	.....
Turbulent	89	..	..	..	..	..	..	..	..	..	..	89	....	.....
Totals	6014	74	134	243	56	122	23	11	3	8	674	6688		

as the wounded. Skull, 14; upper jaw, 1; lower jaw, 2; clavicle, 3; scapula, 2; humerus, 13 (amputation of arm, 2); ulna, 2; spine, 2; ribs (with chest penetration), 5; pelvis (crest of ilium), 1; femur, 12 (amputation of thigh, 2); tibia and fibula, 14 (amputation of leg, 6); tibia, 2; fibula, 3; pulping of foot, 1 (amputation). There were several cases of eye injury requiring enucleation, and many of injury to the hands or feet necessitating amputation of fingers or toes. In the majority of those shown as slightly wounded, the lesions were lacerated wounds of the soft parts produced by minute shell splinters, splinters from parts of the ship or by shrapnel, the last named being few in number.

Burns.—Certain relative factors in the production of this class of injury may be conveniently referred to here. The large number of deaths from this cause resulted principally from cordite ignition; and in the surviving wounded this type was more extensive and suppurated more freely.

In some cases the actual cause of the burn could only be defined with difficulty; in others the patient's own statement had to be relied upon. Of 206 cases under treatment in our hospitals on shore, 126 were due to flash from shell explosion and 80 by cordite ignition: in 139 the burns were of the first and second degrees by the Dupuytren classification, but in 67 penetrated to the third degree in parts of the body, and in 9 to the fourth degree. Among these cases it cannot be said that the degree of the burn varied according to the cause, but probably only the milder form of burn resulting from cordite ignition came under treatment. The exposed parts of the body, such as the face, neck, scalp, and extremities, were burnt in almost all cases, either singly or collectively, but in 15 the trunk was also affected.

The total percentage of wounded in relation to the complement has been worked out in 11 instances in order that some estimate may be made of the possible number of casualties which the surgeon will be called upon to dress. In conclusion, these figures only represent the statistics on one side of an indecisive naval action, and, therefore, whatever deductions are made from them, this important fact must be given ample consideration. On the other hand, it should not be forgotten that the battle of Jutland represents the greatest naval action in the history of the world from the statistical records of the numbers of killed, wounded, and ships engaged.

Accommodation for the Wounded.—Hitherto the primary needs of a peace-time routine have prevented this question from receiving its due measure of appreciation; and it is hoped that the experiences gained in action will bring a very real advance in the provision of adequate accommodation for the wounded. The degree of success of any scheme in this respect will be proportional to its simplicity and the ease with which it can be adapted to meet any force of circumstances. Elaborate methods, requiring arduous preparation and allocation of spaces for a specific purpose, are doomed to failure in practice under war conditions. Maclean[4] and McCutcheon[5] both draw attention to the fact that their prearranged organization for dealing with casualties was completely

upset early in the action by an explosion. Since the needs of the injured must always remain subservient to the fighting power of the ship, a compromise must be sought; and it is suggested that there is ample scope for providing many of the permanent fittings for a dual purpose. Were such a scheme thoughtfully carried out it would be possible to improvise a hospital ward in the most accessible space which is left undamaged—an almost ideal situation.

In any case, a certain portion of the ship must be set apart for nursing the wounded; should they remain scattered in compartments here and there efficient supervision becomes impossible. Such features as warmth, adequate ventilation, and proximity to the upper deck in case of the ship being sunk while returning to harbor will greatly influence the surgeon in arriving at the correct decision. The sick bay, if undamaged, will receive those most dangerously wounded. The ward room, gun room, or captain's cabin will at once suggest themselves for the overflow in a big ship; in the light cruiser the space beneath the forecastle or a portion of the mess deck adjacent to a main hatch may serve; in a destroyer the forward mess deck, the cabin flat, or captain's cabin aft offer the only means of refuge.

Cots, mess tables, stretchers, and the decks themselves all contribute toward providing the required number of "beds." Cots are limited in use to the sick bay. Their size prohibits their undoubted value being turned to account elsewhere in the ship. Mess tables may be converted into temporary beds. Being firmly fixed, they are most suitable for fracture cases. In addition, they are accessible, always ready, and conveniently raised from the damp and draft of the deck.

In light cruisers where the deck space is so diminished some form of tier system as suggested by Lavertine and Bringan may be employed with advantage. The bamboo stretchers are slung one above the other on wire ropes suspended from the deck above.

The decks themselves also possess certain good points. The sailor is accustomed to sleeping on them; they provide a steady support for a mattress; and the patient can be dressed and nursed without difficulty. Penfold[3] prefers this to the tier method. If the state and position of the deck meet the requirements mentioned above, its very simplicity is sufficient recommendation for its employment.

Choice of Operating Theater.—Many ships are now fitted with a detached operating theater, and the propriety of such an arrangement cannot be doubted for a peace-time routine; but during war its value can readily be exaggerated. To render such a space immune from the effect of shell fire its position should be well below the upper deck, and here the provision of accessibility from the different parts of the ship will prove almost an insuperable obstacle. In designing any set plan for any type of fighting ship it is well to remember that no one can foretell the amount of damage a ship will sustain in action nor where destruction will occur. Consequently, it appears more feasible to improvise an emergency surgery in the most suitable position near the upper deck after the action is over. In selecting this the surgeon will

be influenced by such essential requirements as good light, natural ventilation, an adequate water-supply, and proximity to the place where the wounded will afterward be accommodated.

Anesthesia.—Previous paragraphs (Vol. IV, p. 1024, and Vol. VI, p. 758) discuss this question fully; and the main principles advocated there still hold true. Spinal and local anesthesia, however, so admirable in theory, are hardly practicable after action. Livesay[24] considers spinal analgesia of great benefit in peace, but quite inexpedient for dealing with a rush of cases in war; and the general consensus of opinion supports this view. The degree of success which spinal anesthesia can confer depends to a very large extent on the correct attitude of the patient, a quiet environment, and the observance of rigid asepsis—three fundamental conditions which are frankly impossible to obtain after a ship has been heavily engaged. Furthermore, the psychic plight of the wounded, excellent though it may be in many respects, at once precludes any attempt to operate so long as they are conscious of their surroundings. The natural and common desire of all is to be "put to sleep" so as to forget for the time being the ordeal through which they have passed. This temporary calming of the excited mind by a general anesthetic invariably exerts a beneficial influence on the course of the case. Again, the high percentage of burns of the face and hands together with the preponderance of multiple injuries and the limitation of the area of insensibility to regions below the umbilicus further militate against its general employment after action. Finally, spinal anesthesia cannot as yet be considered so simple, so safe, and so certain as the occasion demands.

The evidence overwhelmingly favors chloroform as the most desirable anesthetic; in fact, Muir[14] goes so far as to say that it is the only suitable one. Maclean[4] used C. E. mixture with excellent results; 28 cases were placed under a general anesthetic in this instance. Ether is, of course, contraindicated in all patients who have been exposed to the effects of fumes and smoke. That such volatile liquids become a source of danger if used in a confined space cannot be denied, but the wise surgeon will select his operating theater in the knowledge that ample ventilation is a primary requirement.

Antiseptics.—To enter into a discussion on the relative merits of the various substances classed as antiseptics forms no part of the purpose of this chapter, but it is expedient to analyze the advantages and disadvantages of certain solutions in order to discover those which are most desirable to meet the needs of the surgical work afloat. Such qualities as portability, simplicity of preparation, freedom from the dangers of toxic absorption, and the possession of a high germicidal power in the presence of albuminous fluids will greatly influence the surgeon in making his selection. No "fool-proof" antiseptic has as yet been devised. Each one possesses to a greater or less degree some idiosyncrasies which must be taken into account to obtain the best results; and, consequently, the choice of any single one will be governed by the intelligent display of the individual surgeon's experience.

For superficial wounds $2\frac{1}{2}$ per cent. iodin in spirit has borne the test of practical efficiency well. In every instance medical officers testify to the satisfactory results obtained. Opinion is not so unanimous with respect to the attempt to render extensive lacerated wounds aseptic. Perchlorid of mercury, biniodid of mercury in spirit, peroxid of hydrogen, carbolic acid, both pure and diluted, emulsions of the coal-tar derivatives, permanganate of potash, and the alkaline hypochlorites all

found their respective advocates among British naval medical officers. Pastes containing carbolic acid or iodoform gave most disappointing results, and cannot be recommended. Solutions of the alkaline hypochlorites, such as eusol, Carrel-Dakin's and Labarraque's fluids, have come greatly into prominence during the recent war. In many respects these approximate the ideal as a general antiseptic for use on board a fighting ship of any description. Eusol holds a distinct advantage in its simplicity of preparation, and partly for this reason Maclean[17] adopted it for cleansing all wounds and burns; 57 cases were thus treated, the majority of whom suffered from multiple injuries. Such was the pressure of work that many were forced to forego the preliminary washing with soap and water; 14[55] of the most severe cases, comprising 24 injuries, were examined in a hospital ship a fortnight later; 17 were aseptic and 7 had suppurated. Of the latter, in 3 pieces of clothing were subsequently removed, while in 1 a small piece of shell was found in a metatarsal joint. No antiseptic will compensate for errors in surgical technic, and the latter can only be lessened by granting the operator every available facility. In the instance quoted above half the medical staff was depleted by casualties, and the lack of water at the outset enhanced the difficulties of dressing the wounds.

Delay in the early treatment of wounds is well shown by Darby's[6] experience when he attended the German wounded from the Emden forty-eight hours after injury. All were acutely septic, with maggots $\frac{1}{4}$ inch long crawling over the exposed tissues. The temptation to employ strong antiseptic solutions, such as a mixture of 1 : 500 perchlorid of mercury and 1 : 20 carbolic acid, is no doubt great, but nevertheless should be resisted. Free lavage with hot saline or flushing with eusol will produce better results. Powerful corrosives will devitalize the already inflamed tissues and lower their resistance to infection, whereas the main object in view is to remove the principal foci of infection and assist the natural agencies of the body to overcome the minor centers. Some authorities follow this practice to the extent of irrigating with hypertonic saline and dressing the wound with gauze and sodium chlorid tablets. Such a method cannot be recommended as a routine on board a fighting ship. Frequent changes of the dressings are required, which is an important matter to be avoided if possible. Besides, the tissue fluids may not be able to stand the strain of such a powerful lymphagogic effect as that produced by a salt pack.

Disposal of the Dead.—This urgent and important problem requires careful consideration, although the actual arrangements for dealing with it do not come within the limits of the surgeon's duties. Both Penfold[3] and Muir[14] found the practice of screening off a portion of the mess deck as a mortuary very unsatisfactory. From the hygienic standpoint the dead should be removed from compartments and passages below as soon as possible to the upper deck. The stench from burnt and mutilated bodies lying between decks soon becomes unbearable and seems to permeate the ship for several days afterward. The important matter of identification is not infrequently difficult and at times

impossible. In one instance no trace of a missing ward room messman was discovered save a few battered links of his watch-chain. After

FIG. 76.—CASE A. CORDITE BURN OF FACE. SECOND AND THIRD DEGREE. SECOND DAY. (Courtesy of Temporary Surgeon Lt. C. P. G. Wakeley, R. N.)

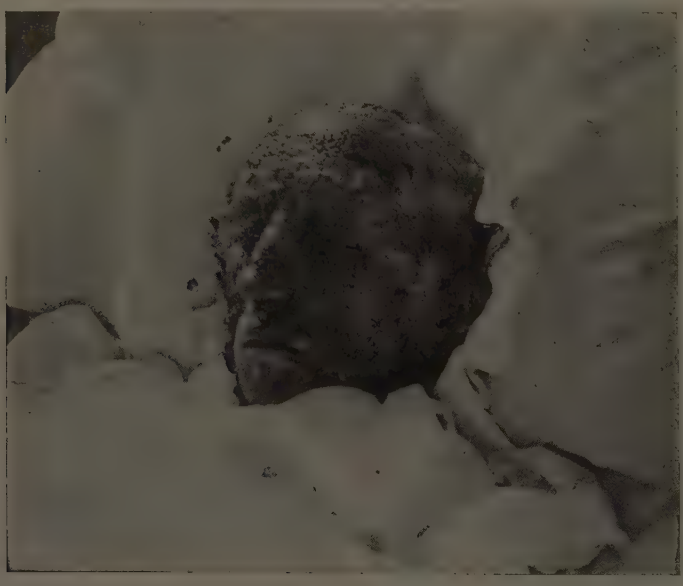

FIG. 77.—CASE A. SEVENTH DAY. (Courtesy of Temporary Surgeon Lt. C. P. G. Wakeley, R. N.)

identification the bodies are sewn up in their hammocks, weighted, and committed to the deep in a fitting manner. Such a procedure can be

defended as the only rational one to adopt under the circumstances. Probably no other sight disturbs the morale of the men so much as observing a dead shipmate lying on the deck apparently uncared for. Prior to removal to the upper deck it is wise to cover the body with the flag, since the reaction after the excitement of the battle renders the sailor's mind very prone to morbid sentiment.

Treatment of Burns.—Owing to their peculiar nature and the high mortality associated with those of the third and fourth degree, burns have assumed a position of remarkable importance in naval surgery;

FIG. 78.—CASE A. FIFTEENTH DAY. PRIOR TO SKIN-GRAFTING. (Courtesy of Temporary Surgeon Lt. C. P. G. Wakeley, R. N.)

and their treatment demands the utmost care and attention from the surgeon. Probably the sharp discussions which have arisen in connection with the most suitable dressing are responsible for obscuring to some extent the main principle. For it must be remembered that unless the cardinal laws for mitigating infection are strictly observed, the choice of any specific local application fades into insignificance. To further this primary aim all burns must receive a most thorough cleansing, preferably under a general anesthetic, as soon as possible, and their progress toward recovery will denote the pains that have been

taken in this process. In referring to this problem Hopkins[18] points out that greasy applications prolong this operation and consequently are not ideal for a first-aid dressing.

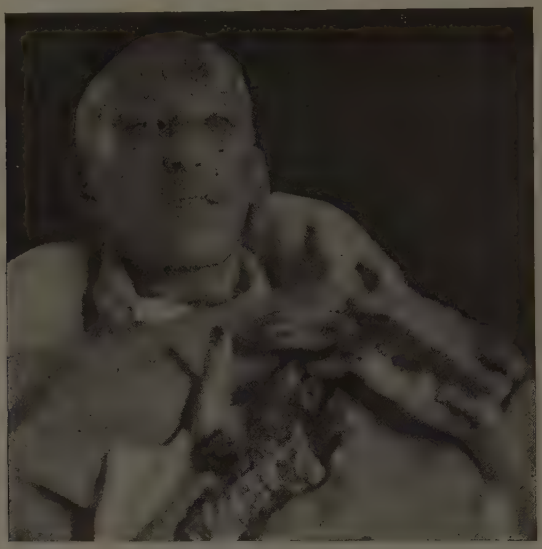

FIG. 79.—CASE A. THREE WEEKS. SKIN-GRAFTS ARE OBSERVED. (Courtesy of Temporary Surgeon Lt. C. P. G. Wakeley, R. N.)

FIG. 80.—CASE A. TWO YEARS AFTER THE INJURY. (Courtesy of F. B. Wright.)

Picric acid has been in general use for the first application, since it is simple to distribute and apply; in addition, it is more likely to be put

on clean than any other form. As a permanent dressing the prevailing opinion is opposed to its employment. Penfold[3] and Maclean[4] con-

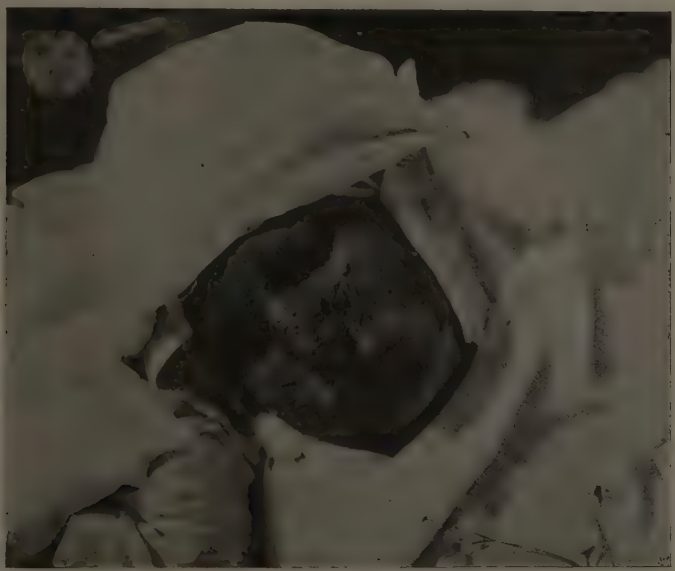

FIG. 81.—CASE B. BURNS OF FACE DUE TO SHELL EXPLOSION. AFTER TWO WEEKS' TREATMENT. (Courtesy of Temporary Surgeon Lt. C. P. G. Wakeley, R. N.)

FIG. 82.—CASE B. SHOWING HANDS AS WELL. AFTER FOUR WEEKS' TREATMENT. (Courtesy of Temporary Surgeon Lt. C. P. G. Wakeley, R. N.)

sidered it unsatisfactory; Muir[14] felt that it did not help to control sepsis, while Bunton[8] alludes to the pain and discomfort it provoked. Git-

tings[28] prefers iodin for burns of the first and second degree and picric acid for those of the fourth degree.

After the burn has been cleansed the choice of the most suitable dressing will depend on the inclinations of the individual surgeon. Although surgical opinion as a whole is strongly opposed to the employment of oily preparations, the majority of British naval medical officers preferred them. Whatever imperfections are attributed to them, the clinical results obtained on board ship after action left no doubt as to their efficacy for the treatment of the type of burn alluded to above. *Sterile* olive oil formed the basis of these, to which menthol or eucalyptus oil were added in small quantities. Applied on a single

FIG. 83.—CASE C. BURNS OF FACE DUE TO SHELL EXPLOSION. AFTER THREE WEEKS' TREATMENT. (Courtesy of Temporary Surgeon Lt. C. P. G. Wakeley, R. N.)

layer of lint they are simple to use and easy to change. Relief from pain was marked; suppuration was very greatly diminished; stink was abolished. Wakeley[20] warmly recommends this method, and his illustrations bear witness to the degree of success achieved.

A 1 per cent. aqueous solution of aluminum acetate is a useful dressing for burns of the first and second degree, but it occasionally gives rise to irritation, of which the patients complain as "itching."

The paraffin preparations (see "Burns" in the chapter on the Skin) are extremely valuable, and will doubtless be extensively employed in the future. Probably they will supersede all the above-mentioned methods. The "candle" form of application is preferable to that of the spray, for use on board ship, by reason of its simplicity.

Treatment of Secondary Wound Shock.—See the chapter on Shock.

Outside the Radius of Action.—When the captain deems the ship outside the range of further action and the "secure" has been sounded, the activities of the surgeon will enter upon a second stage in the practice of emergency surgery. Much will depend on the number of hours the ship will take to reach her base, a neutral port, or hospital ship, where the wounded can be discharged. The narrow confines of the North Sea reduced this period to an average of forty hours; but if we take the case of the duel between the Sydney and Emden, several days elapsed before additional assistance could be sought. Varying circumstances will therefore modify the course of procedure which the surgeon will pursue. Bunton[19] considers that only amplified first aid

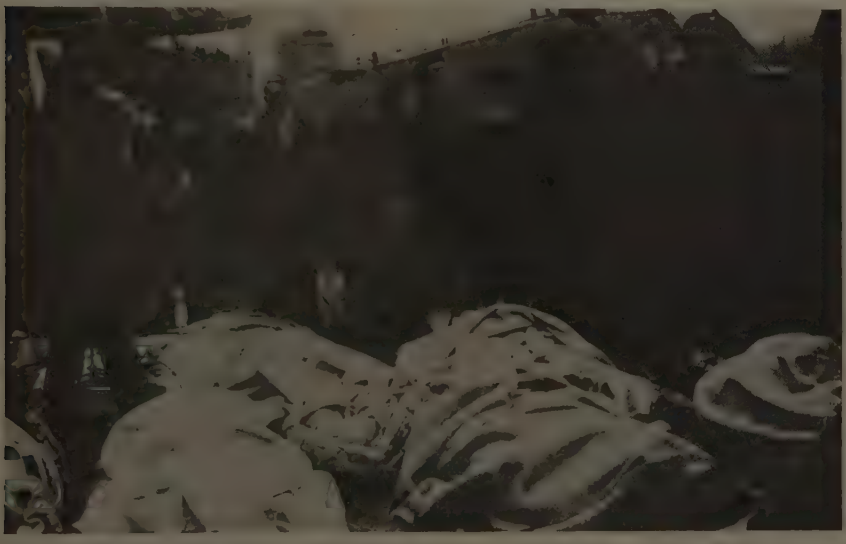

FIG. 84.—WOUNDED BROUGHT UP FROM BELOW PRIOR TO TRANSHIPMENT AT SEA. THE SHIP SANK WITHIN HALF AN HOUR OF THIS INCIDENT. (Courtesy of Temporary Surgeon Lt. A. T. McDonald, R. N.)

and imperative operations should be carried out. In a destroyer where the facilities for operating are negligible such principles hold good; but in a battleship, battle cruiser, and even light cruiser this line of thought will not commend itself, and considerably more may be attempted and successfully achieved. Weather conditions, the number of casualties, the length of time before the ship makes harbor, and the state of the ship herself must all be taken into consideration. Probably no other group of circumstances serves to expose so freely the qualities of a good surgeon, and the personal element is paramount. Fortified by a thorough knowledge of his work his decisions should be bold—distinguished by common sense and a just appreciation of his own limitations. The ultimate progress of the patient will greatly depend on the thorough manner in which the wounds have been treated in the early stages.

The possibility of another action or the chance of being torpedoed while returning to the base must always be borne in mind, since these will determine to some extent the disposition of the wounded. In the former case operative measures under general anesthesia must be disregarded, as they only become practicable when outside the radius of action. In the latter contingency the light cruiser is at an advantage compared with the battleship or battle cruiser, where the wounded have a longer distance to traverse in order to reach the upper deck. Muir[14] emphasizes the need for stretcher parties to be drilled for this specific purpose. In a great emergency man-handling is the only feasible solution; each officer and man takes a wounded pick-a-back. Figure 84 shows an actual case of wounded lying in the battery on the deck of an armored cruiser just before she sank. The photograph was taken under embarrassing conditions at 6.45 A. M. All but one were safely transferred to a sea-plane carrier. One case who had an arm and a leg blown off slipped off a stretcher during transhipment and fell into the water. He was rescued, but ultimately died. When a ship is gradually sinking the mental and physical strain imposed on the wounded and those responsible for their welfare becomes intense. Situated as they are two or three decks below in a big ship, with scanty knowledge of the trend of events above, the sensation of being hopelessly boxed in ceases to be a pathognomonic symptom of disease.

Surgical Toilet.—Emergency surgery does not call for an abundance of instruments; and those supplied to fighting ships amply fulfil all reasonable requirements. At the same time it seems convenient to refer to a few practical suggestions which are offered to improve the efficiency of the operative technic and indirectly the comfort of the patients. For sterilizing instruments the mess kettle or "fanny," heated in the galley, acts as an admirable substitute for the usual type. Methylated spirit lamps and electric heaters are not infrequently rendered unserviceable during an action. Colborne[23] has noted the utility for providing rubber feet for the operating table, so that it can be moved to any desired position—a point of the greatest importance. The desirability of surgeons operating in rubber gloves is obvious; and there is no need to dwell on the necessity for preparing an adequate supply of sterile swabs and compresses beforehand. The demand for ligatures and sutures will be met by silkworm-gut for the skin, varying thicknesses of catgut for buried sutures, and thin silk for any urgent intestinal work. To overcome the difficulty of providing for each surgeon his favorite needle the slotted pattern illustrated is simple and effective for rapid emergency surgery. No time is lost in threading, and it is very easy to handle. The metal tourniquet shown in the diagram (Fig. 86) was devised by Sir George Lenthal Cheatle, and this pattern marks a decided improvement on the India-rubber variety for use in a ship. Its chief advantages lie in the ease of application and the accuracy with which it can be adjusted to flush the tissues when required. The instrument itself consists of a chain and securing hook controlled by an operating screw with a hand wheel. The bridge is

applied over the point of compression. A towel should separate the apparatus from the skin, and the whole can be sterilized by boiling.

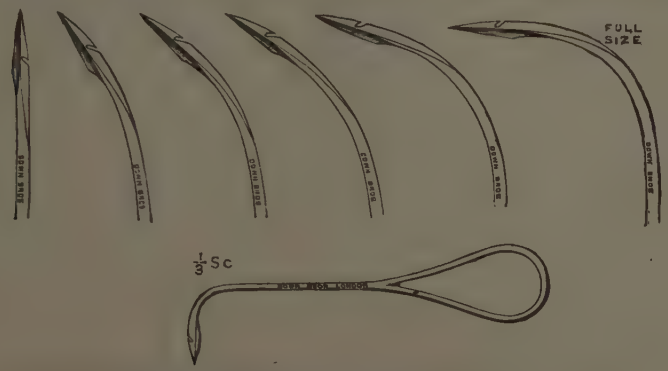

Fig. 85.—Slotted Needle Recommended for Emergency Work After Action at Sea. (Courtesy of the manufacturers, Down Bros., Ltd., London.)

Acute infections in the form of *gas gangrene* and *tetanus* have not developed in naval casualties, and for this fact the surgeon has much to be thankful. However, it cannot be said that the work entailed in mitigating infection is materially diminished thereby, since extra-

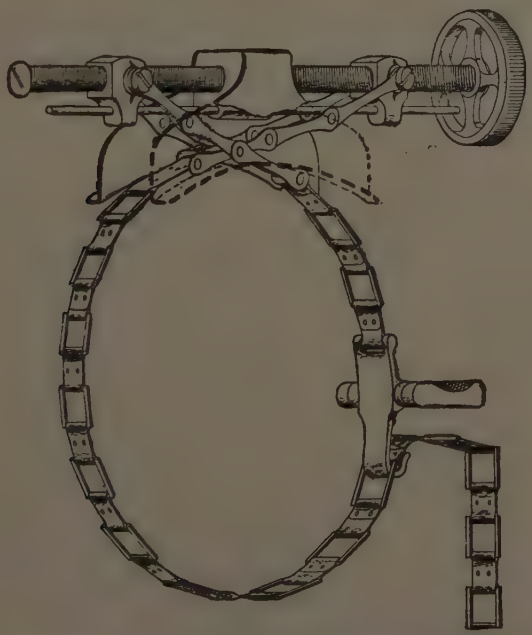

Fig. 86.—Metal Tourniquet Devised by Sir G. Lenthal Cheatle. (Courtesy of the manufacturers, Messrs. Mayer & Phelps, London.)

ordinary care and attention are required to render wounds aseptic. The importance of preventive measures in this respect cannot be overestimated, and the naval medical officer possesses the great advantage

of being early on the scene; but the limitation of his resources by reason of the surroundings neutralizes this asset to an appreciable extent. It has been seen that the first-aid method of spraying with iodin and dressing with cyanid gauze is but an attempt to prevent heavier infection, and now the time is at hand when more thorough treatment becomes imperative.

At this stage Muir[14] has drawn attention to the need for systematic examination of every patient, as injuries to the eyes, ribs, back, and buttocks are liable to be overlooked. When under the anesthetic search for these should be made and, whenever found, noted at the time, so that on discharge to the hospital ship a concise and complete description accompanies each man. In carrying out this investigation the greatest gentleness should be exercised in manipulating the injured parts if shock is to be minimized.

Character of Wounds.—Stevenson's general description of shell wounds which is quoted on page 1047, Vol. IV needs no elaboration, and the accompanying illustrations accurately depict the type of injury observed in the recent war at sea. Contusions and lacerations present such an infinite variety in the different localities that they defy a detailed analysis. Their features closely resemble wounds produced by machinery accidents in industrial centers ashore; and they contrast with those met with in military surgery by the absence of contamination with earth—a fundamental difference.

The irregular pieces of steel into which the shell bursts vary enormously in size, some being as small as a peppercorn, others weighing scores of pounds. They produce wounds which are characterized by great loss of tissue and much splintering of bone. Soft parts, as the subcutaneous layers, fasciæ, and muscles, are bruised and rent to a remarkable degree—as though some animal had clawed a lump of flesh piecemeal out of the body of its prey. Small entrance wounds with clean-cut edges are conspicuous by their absence. Fragments which lodge in the tissues create great havoc and invariably carry clothing before them. It is most remarkable the manner in which large jagged pieces of shell pass through such small entrance wounds in the skin. The superficial tissues appear to come together in an attempt to bury the missile.

The track of fragments of shells is usually seared as if with a cautery and the muscles are colored a deep brown tint. There can be no doubt that the tendency to primary hemorrhage is checked by this factor. The high temperature of the fragment itself may be ascribed partly to the detonation of the bursting charge, but principally to the resistance of the armor in arresting its flight whereby much of its energy is converted into heat. Girard considers that the temperature of a rifle bullet does not exceed 150° F. in the air, but there can be no true analogy between that and a mass of steel weighing 1300 to 1500 pounds. It is highly probable that the fragments from an enormous armor-piercing projectile possess a higher temperature than those from the lighter shells; and consequently, the cauterizing phenomenon is more

likely to be seen in the larger ships with good protection than in light cruisers or destroyers.

Superficial Wounds.—In dealing with any wounds of the soft parts cleansing of the skin in the immediate vicinity is a prime essential. Ether soap is useful for the purpose and a spirit lotion of mercury biniodid or iodin is then applied. The wound itself is freely opened up so that the condition of the subcutaneous tissues can be noted in detail; any foreign bodies, especially tags of clothing, are removed at once. A prompt decision must then be made. If the surgical toilet has been thorough, complete excision and primary suture is the method of choice. The amount of success in this procedure will be measured by the capability of the surgeon, for, if the bounds of common sense be overstepped, the practice is liable to abuse.[27]

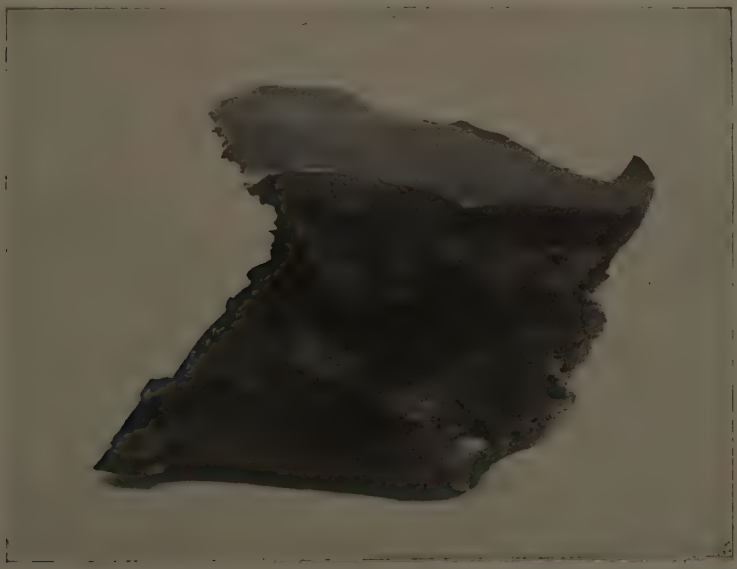

FIG. 87.—A TYPICAL FRAGMENT OF ARMOR-PIERCING SHELL REMOVED FROM BUTTOCK. THE CURLED-UP EDGE AND JAGGED PROJECTIONS PICK UP CLOTHING WITH EASE AND CARRY IT INTO THE WOUND. PRIMARY HEMORRHAGE WAS NEGLIGIBLE IN THIS CASE, ALL THE MUSCLES BEING SEARED BY THE HEAT. WEIGHT, 17½ OUNCES. (Author's case.)

Deep Penetrating Wounds.—In these the damage below the surface is frequently greatly in excess of that visible to the eye. A free incision is therefore required, but extensive exploration of deep-lying structures cannot be justified unless hemostasis is the object. Once the wound has been opened up, as little as possible is attempted, and anything in the nature of dissection rigidly avoided. Tissues that are manifestly devitalized must be excised, remembering that injured muscle demands the utmost solicitude and care. Rough handling of muscular bellies is penalized by a proportionate increase in the amount of secondary wound shock. Strips of fasciæ and tendons which are hanging loose are best removed by the scalpel, as these invariably slough, owing to their poor vascularity. Fragments of bone lying free may be taken

out without any misgiving, although the question of total esquillectomy has not been definitely settled. By such procedure the surgeon will render the wounds eligible for *delayed primary suture* at a later period.

Perhaps the most important and difficult part of the operative technic lies in rendering hemostasis as complete as possible. In this matter Cheatle's metal tourniquet will prove of great assistance. Swabbing will be reduced and a clear view of the different structures is obtained thereby. Pressure on the main vessels is controlled by a single turn of the screw. Large arteries are ligated at the site of injury or at a distance. Nerve suture is quite out of the question, but section and injury of nerves are carefully noted for the information of the surgeon who receives the case at the shore establishment.

Deep, ragged, lacerated wounds are cleansed conscientiously in a similar manner. Primary suture is contraindicated absolutely, and such wounds may be safely left open after flushing with saline or eusol and the establishment of free drainage. Although the Carrel-Dakin method cannot be employed in a ship, the principle can be imitated by inserting a piece of drainage-tubing to the bottom of the cavity and packing lightly round with sterile gauze. The tube or tubes thus left in position project from the surface. Consequently, the deep parts of the wound can be flushed intermittently by eusol or any other suitable antiseptic. The great advantage of this method becomes evident in the subsequent treatment; while on board or during transport the dressings need not be removed, whereas fresh antiseptic can always be applied to the depth of the wound at two-hourly intervals by means of a syringe with India-rubber bulb. However extensive and lacerated an injury may be, acute sepsis or gross infection can be overcome by an intelligent application of these principles, and the majority of wounds will reach the hospital ship ready for delayed primary suture.

The administration of antistreptococcic serum or a polyvalent vaccine to the wounded immediately after action is a practice justly open to criticism. Deficiencies in operative technic, whether due to the inexperience of the surgeon himself or the conditions under which he works, cannot be compensated for by the introduction of serum or vaccine therapy. Such methods belong to a hospital well equipped with a modern laboratory and a staff skilled in bacteriologic technic, and hold no place in the kit of a surgeon in a fighting ship after action.

Finally, there is always considerable difficulty in bringing the edges of the wound together where much loss of tissue has taken place. This is not a matter of great moment so long as it is recognized that no tension is left on any buried sutures and that these should be as few as possible. Supporting sutures of the loop variety materially prevent the tendency for the wound to gape. Pledgets of gauze or small pieces of rubber tubing will prevent the loops from cutting through the skin.

Dressings.—These are kept in water-tight metal boxes. The white sterile gauze wrung out in some antiseptic, such as eusol or 1 : 40 carbolic acid, is preferable to that impregnated with the double cyanid of mercury. Tissue fluids escaping from the wound dissolve

the metallic salt, and thus a highly irritant solution is formed which is very liable to produce a severe dermatitis on the already damaged skin. Sphagnum moss, as suggested by Bankart,[21] is perhaps an improvement on cotton-wool, provided it is carefully prepared. He states it is a better absorbent; certainly it is less expensive.

Splints.—The great variety of fractures which may involve any bone in the body necessitates the adoption of a universal splinting material; and the aluminum alloy introduced by Sir Frederick Treves and advocated by Max Page[29] serves this purpose admirably. This substance is almost ideal for emergency work on board ship. It is easy to mold into the required shape; it takes up little space; it is light and serviceable, and in use it is efficient. Muir imitated these principles by securing several lengths of wood $\frac{3}{8}$ inch thick, 3 to 5 inches broad; from these he cut splints according to his needs. Gooch splinting has proved convenient and satisfactory.

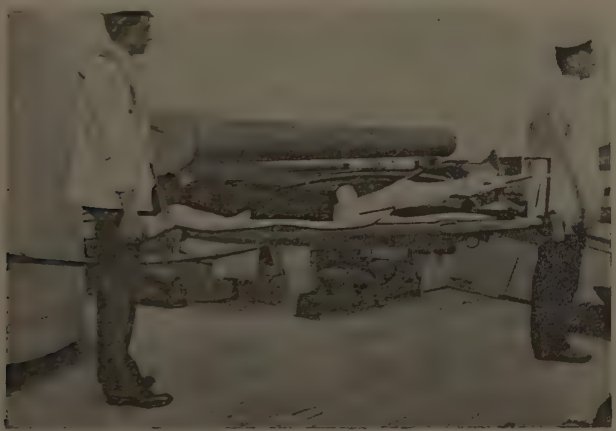

FIG. 88.—THOMAS' SPLINT IN USE ON BOARD SHIP AS SUGGESTED BY SURGEON COMMANDER C. V. GRIFFITHS, R. N. A GALLOWS CONSISTING OF A STEEL CROSS-BAR AND TWO UPRIGHTS, MADE IN ONE PIECE, IS FITTED TO THE FOOT OF A BAMBOO STRETCHER. THE LIMB IN THE SPLINT IS FIXED TO THE GALLOWS. BY THIS MEANS BOTH TREATMENT AND TRANSPORT OF FRACTURED FEMUR ARE FACILITATED. (Courtesy of the Editor of the Journal of the Royal Naval Medical Service.)

Fractures of the humerus are best dealt with by employing the splints advised by Hey Groves or Sir Robert Jones; the excellent abduction splint devised by Swan is disadvantageous in a ship only by reason of its bulk.

The very important subject of fracture of the femur and its treatment either by direct or indirect extension has been fully dealt with in many treatises. Indeed, the army medical authorities set apart whole hospitals for this particular injury alone. Extreme difficulty has always been experienced in obtaining any sound method of extension on board prior to the introduction of the Thomas knee splint. It is hardly necessary to state that indirect extension by means of weight and pulley is wholly inapplicable in any ship after action. Most of the cases of fractured femur are compound and require anesthesia for

cleansing the wound; and the surest method of obtaining a satisfactory result is by direct extension and immobilization in a Thomas knee splint. Griffiths[22] has adapted the principles of the splint to meet naval requirements, and his illustration demonstrates the mode of using it. The splint possesses the virtues of lightness, rigidity, and ease of application; consequently, this modification deserves a wider recognition.

A large number of the diverse varieties of splints are out of place in a fighting ship and only occupy valuable space in the medical distributing stations. The employment of calipers or transfixion pins, inclined planes, Hodgen's splint, Sinclair's net bed, or Balkan frames may safely be left to the care of the staff in a hospital ashore. Their supreme advantages for certain cases is universally recognized, but their adoption in any fighting ship is impracticable, and this fact must be freely admitted. Finally, the claims of the Neil Robertson stretcher, which acts as a splint for the whole body, cannot be overlooked. For general purposes it has amply proved its worth.

Amputation.—See the chapter on Amputations.

Regional Wounds.—Abdomen.—No analogy can be drawn between abdominal wounds caused by a bullet and those produced by shell fragments. In the latter a large part of the abdominal wall is frequently torn away and the viscera terribly mutilated—a condition at once beyond all surgical aid. The lesions are so gross and shock so pronounced that little can be done except to relieve the suffering with morphin. No case of recovery from intraperitoneal injury due to a shell splinter has been recorded on board ship.

A full and complete laparotomy is impossible; in fact, any abdominal work is out of the question in a light cruiser. In a battleship under the most favorable conditions such operations are fraught with danger and should only be undertaken as a last resort, as, for instance, in a case of intraperitoneal hemorrhage. In isolated cases Murphy's method, consisting of a small incision above the pubes, drainage of the pelvis, and the adoption of Fowler's position may be indicated, but such are extremely rare. If the surgeon is in doubt of himself, or his equipment, or that the time occupied will prevent his attending more urgent cases, abstention from intervention is always justifiable. Only very exceptional circumstances can excuse opening the peritoneum to remedy the damage caused by shell fragment on board a fighting ship after a naval action.

The Skull.—The operative treatment for fractures of the vault and vertex together with that for meningeal hemorrhage do not call for comment beyond emphasizing the fact that only urgent cases should be dealt with. In the event of a shell splinter entering the brain substance no attempt is made to remove it. Such a foreign body is aseptic, and the tendency for the wound to remain so is greater than those met with in other regions of the body. Intervention in these penetrating wounds of the skull will probably aggravate the condition by disseminating any infection present. The scalp is shaved and the edges carefully disinfected in an attempt to localize the injury by assisting

the formation of protective meningeal adhesions. Brain substance, like other tissues, swells when injured, and thus the natural forces come into action, shutting off the area from the remainder of the cranial cavity. A thorough examination of the neurologic condition of the patient is quite impracticable on board ship.

Thorax.—Penetrating wounds of the chest wall have been common and generally fatal. The majority die almost at once. If, however, the entrance wound of the pleural cavity is small and the pulmonary substance not grossly injured, much relief is gained by closing the opening with a few deep sutures. Excessive hemorrhage is checked by the formation of a hemothorax. No form of intrathoracic surgical work can be undertaken; even aspiration should only be employed when extreme dyspnea results from a large pleural collection.

Postoperative Treatment.—When the operation has been completed and short notes have been made, the patient is removed to the space allocated for the reception of the wounded, where he is succored until harbor is reached. Nursing is exhausting work under the conditions that prevail, but valuable assistance comes from every quarter, and so the task of the medical staff is lightened considerably. Attention to the personal needs of the patient add greatly to his comfort; in this connection it should be noted that such utensils as feeding cups, goose necks, and bed-pans made of aluminum are preferable to those of earthenware, as the latter are very apt to be broken.

A keen look-out has to be kept for reactionary hemorrhage and retention of urine. Bandages frequently require readjustment owing to the swelling of the soft parts. Redressing a wound after it has been put up should be avoided if possible; in attaining this end eusol can be applied without disturbing the dressing, and this is an important point when the casualties are heavy. Diet consists of milk diluted, bovril, soups, and bread and butter. Thirst is perhaps the most prominent symptom, and small quantities of water, little and often, provide the most satisfactory remedy. Tea or cocoa may be preferred by the less seriously wounded. The ship's variety of cocoa is liable to produce vomiting and the peptonized kind seems more suitable. Tobacco is a valuable therapeutic agent at this stage. When secondary wound shock is present the intense thirst is markedly relieved by rectal salines with the addition of a little glucose, and possibly bromid of potassium. Even this simple operation preceded by an enema presents many difficulties on board a ship where the accommodation is so limited that the patients may be lying on the deck.

Finally, all are labeled; the form of label is modeled on the lines of that employed by the American Army authorities. A length of thin copper wire fixes it firmly to the clothing. This procedure is of immense assistance to the staff of the hospital ship which may receive 300 to 400 cases within the space of two hours.

Transport to Hospital Ship.—Except in a dead calm this process is too hazardous to attempt in the open sea. The difficulty of bringing large ships alongside each other and keeping them in that position for

the purpose of transhipping cot cases must be apparent to all. Darby[6] refers to this perilous undertaking when an armed liner took off some of his less severely wounded in mid-ocean; and we have already seen an instance where the injured had to be removed from a sinking ship.

The ideal method, from the surgeon's point of view, is for the hospital ship to come alongside the battleship in harbor, but this is rarely practicable, as the fighting ship is already being prepared to put to sea again; the removal of the wounded is only a part of the whole. The wounded are brought to the upper deck through the ammunition hoists and then transferred over the side to the decks of lighter or smaller craft below. This is a matter of seamanship and is, therefore, best left to the executive officer to deal with. The cots and bedding should be provided by the hospital or depot complete with hot-water bottles. The wounded are then placed therein from the stretchers or mattresses which have done duty as beds. Duly ticketed with short notes on their injury and treatment, they are taken away, and only then do they realize the immense relief from noise and discomfort inseparable from a fighting ship.

It is unwise to recommend wounded for return to the ship on recovery. Penfold states that out of 20 which did return, 5 had to be ultimately discharged with neurasthenia and the others suffered to a greater or less degree. He also notes one case of traumatic insanity, which was subsequently certified, but this is rare.

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CHAPTER XI

TRAUMATIC SHOCK

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War provides unusual opportunity for observations on shock due to injury because in warfare men are constantly receiving the sort of injuries which in civil life occasionally induce the condition, namely, those which rupture, shred, tear, or crush large masses of tissue. During the Great War of 1914–18 the opportunity provided for studying traumatic shock was utilized by French, English, and American observers. A considerable amount of new information was thus obtained on this condition long recognized as mysterious.

The wounds which induce shock are likely to be associated with hemorrhage and infection. It is necessary to distinguish as clearly as possible the phenomena of shock from those resulting from these concomitant conditions. This may be difficult, especially after severe hemorrhage, because, as will be seen later, at a certain stage of shock the conditions resemble those induced by hemorrhage. Cases have been observed, however, in which immediate blood loss was minimal and infection not yet started, and yet a state of shock existed. Similar conditions can be induced experimentally. It may be concluded, therefore, that shock is an entity which exists apart from the attendant factors of severe hemorrhage and infection.

In order that there may be a clear understanding of what is being considered as traumatic shock a description may now be given which later discussion will amplify. It is a general bodily state occurring after severe injury and characterized by persistent reduced arterial pressure, rapid thready pulse, pallor, grayness, or slight cyanosis, sweating, cold skin, thirst, superficial rapid respiration, and usually marked restlessness, and a somewhat dulled mental state. Though this condition has long been recognized as shock, its nature has been so obscure and difficult that theories rather than facts have been advanced to account for it. These theories have had ardent advocates who have argued the merits of their views and have proposed treatment based upon the theoretic assumptions. But fundamentally we have been ignorant. One reason for our ignorance is the relative irregularity of the appearance of shock in civil life and the consequent difficulty of pursuing consistent studies. The circumstances of warfare, however, are such as to permit, at times, systematic examination of large numbers of shock cases instead of infrequent single cases, as in civil life. With such opportunity theoretic considerations should be set aside

and primary attention paid to the facts of observation. When sufficient facts have been gathered, theories will fall or become established according as they fail to fit or actually do fit the facts. In this spirit we shall consider the phenomena of shock. First the facts of observation will be expounded; then an attempt will be made to explain the facts, without, however, an elaboration of theory; and, finally, there will be an application of all the considerations to the treatment of shock.*

FACTS OF OBSERVATION

Primary and Secondary Traumatic Shock.—Cases of shock have been classified by Cowell[1] into primary and secondary. The cases of *primary shock* are usually those in which the wound is so serious as to prove necessarily mortal. The patient suddenly becomes pale, clammy and pulseless, and within a few minutes has a low blood-pressure. From this condition there may be recovery, especially if a change for the better occurs soon; but if the condition lasts for a few hours it becomes indistinguishable from the more or less persistent state of secondary shock.

Secondary shock follows moderately severe wounds, such as uncomplicated compound fracture of the femur, or a lacerating wound of muscle without urgent hemorrhage. It is not seen immediately after such wounds, but appears after the lapse of several hours.

French observers[2] have recognized similar distinctions, but have used different terms: immediate, primary, and secondary. *Immediate shock* is equivalent to Cowell's primary group, *i. e.*, it is seen almost at once after injury. *Primary shock* is equivalent to Cowell's secondary group, *i. e.*, it appears after several hours. And *secondary shock*, according to French classification, is the result of septic infection and other complications superposed on factors effective in producing the primary type in their classification.

The important matter is to recognize that shock may occur immediately after wounding or may develop in the course of time. Since Cowell's simple classification of cases into primary and secondary brings out this distinction, his terms will be employed.

Primary shock is commonly associated with severe hemorrhage and may be due directly to that. It has also been described as occurring in "high-strung" individuals and has been attributed to nervous disturbances. Except in cases of obviously mortal wounds there is common testimony, from various observers in different services, that primary shock is relatively rare.

Secondary shock is likely to appear within two or three hours after the wounding. It may be associated with continued bleeding, but commonly is non-hemorrhagic and unaccompanied by marked or developed infection. Exposure to cold, lack of water, rough transporta-

* The exposition and discussion which follow are based largely on experience in co-operation with British investigators at a C. C. S. at Béthune during four months of 1917, in London during three months of the winter of 1917–18, and on the work of a group in the Laboratory of Surgical Research of the A. E. F. in France during eight months of 1918.

tion, and absence of splinting of broken bones have been recognized as circumstances favorable to its development. These factors may later have their action augmented by infection, especially by the bacilli of gas gangrene.

Superficial Rapid Respiration.—The classic descriptions of shock report a rapid superficial breathing, occasionally interrupted by sighs. In a series of cases studied at Béthune the average respiratory rate in 17 cases was 24; in 7 cases more severe, 28; and in 6 extreme cases, 44.[3] In certain of these latter instances the breathing instead of being superficial was deep and vigorous, as in true air-hunger. Neither immediately after wounding nor at any stage during the transfer of wounded men to the hospital was there seen any evidence of such vigorous or violent respiration as would lead to a marked reduction of the carbon dioxid content of the blood, which has been regarded as an important factor in producing shock.

A Dulled Mentality.—Usually the mental condition of the shocked man is one of diminished interest in his surroundings. He lies apathetic and with occasional turning of the head to one side or the other. In the low blood-pressure associated with gas gangrene infection, however, there may be a very clear intellect even to the end.

The questioning of wounded men regarding pain at the time of being wounded evoked almost uniformly the testimony that the wound itself was not painful. This was especially true of large bruising wounds. Small fragments of metal, driven superficially into the body, may be associated with considerable pain, but such wounds are not commonly attended by shock.

The dulled sensibility of the shocked man has been utilized by some surgeons as a factor in producing a sufficient analgesia to permit operation without full anesthesia.

Persistent Low Blood-pressure.—Though the clinical sphygmomanometer is generally applicable in shock, the blood-pressure is at times so low as to make difficult any diastolic determinations. Furthermore, the pulse may be quite impalpable at the wrist, though audible at the elbow. Both the auscultatory and palpatory methods, therefore, should be employed. In 43 observations of low blood-pressure due to wounds, the systolic pressure ranged between 102 and 52 mm. Hg., but in all but 12 cases the systolic pressure was below 86 mm. Hg.[3]

Shock has been defined as a condition in which the systolic pressure remains below 80 mm. Hg. The discrepancy between this definition and the clinical diagnosis of shock in which the pressure may be above this level is possibly accounted for by the observation that in the early stage of shock experimentally induced the blood-pressure may be maintained by vasoconstriction, with the volume of blood in circulation diminished.

Though there probably is a temporary stage of shock in which, with reduced volume-flow, the pressure is still nearly normal, the persistence of low arterial pressure clearly marks the establishment of shock; and the degree of lowering of the pressure under the normal range may be

taken roughly as a measure of the degree of shock which prevails. If a low blood-pressure continues to fall to a still lower level, the circulation becomes less serviceable, and the tissues actually suffer in consequence. On the other hand, if the low pressure begins to rise toward the normal level, it may be taken, as a rule, as an indication of improvement. The use of the sphygmomanometer as a means of watching the condition of the patient is of unquestioned value.

The Rapid Pulse.—In some cases of shock the pulse may be thready and rapid, though the blood-pressure is but little reduced. With established low pressure, however, a rapid pulse may be expected. In a series of cases studied at Béthune the heart was seldom beating faster than 144 beats per minute, possibly a limiting rate for continued action. The average rates were somewhat below this figure. In the following table the average pulse-rates are arranged on the basis of increased diastolic pressures.[3] It is clear that the average pulse-rates are fairly uniform for different ranges of low pressure.

TABLE I
THE RELATION OF ARTERIAL PRESSURE TO PULSE

Number of cases.	Average pressure.		Pulse.	
	Systolic.	Diastolic.	Average rate.	Range.
5	51	23	133	114–144
9	60	35	134	108–152
13	72	44	133	112–150
8	80	55	133	116–144
7	89	62	128	106–144

Reduction of Blood Volume.—By the injection of the dye, vital red, Keith has estimated in a series of 29 wounded men with low arterial pressure the blood and plasma volumes. Comparison of these values with those obtained in normal men of the same weight showed that total blood and plasma volumes were consistently reduced, though the venous red counts and hemoglobin determinations might be nearly normal. Further, the diminished volumes bore a definite relationship to the severity of the clinical condition. With distinct symptoms of shock the blood volume ranged from 51 to 85 per cent. of the normal, with corresponding reduction of the plasma. Normally an acute reduction of blood volume, *e. g.*, by moderate hemorrhage, is followed by rapid compensatory flow of fluid from the tissues. If the loss of blood is excessive, however, or if there has been severe trauma, the consequent shock is distinguished by failure or by marked delay of spontaneous dilution.

Keith distinguishes three classes of cases: (1) those in which the patient, though pale, has a systolic pressure above 95 mm. Hg., a pulse between 90 and 110, a blood volume not reduced below 75 per cent., and a plasma volume relatively higher (85 to 90 per cent. of the normal)

indicating spontaneous inflow from the tissues; (2) those in which the signs of shock are present, with rapid pulse (120–140), with systolic blood-pressure below 90 (usually 70–80 mm.), with blood volume ranging between 65 and 75 per cent. and with plasma volume between 70 and 80 per cent.—a serious condition; and (3) those with extreme shock (a systolic pressure of 60 mm. or less) and with blood volume below 65 per cent. of the normal.[4]

Recovery from shock is associated with a rise of blood volume.

Concentration of Corpuscles in Capillaries.—Simultaneous counting of the venous and capillary blood, with attendant hematocrit and hemoglobin readings, have revealed a remarkable discrepancy between the two blood samples. The difference between capillary and venous erythrocyte counts may be as great as 2,500,000 corpuscles per cubic millimeter. In the following table is presented a record of these discrepancies.[5] It will be observed that the hematocrit and hemoglobin determinations confirm the discrepancy shown by the red counts.

TABLE II

VENOUS AND CAPILLARY RED COUNTS, WITH HEMATOCRIT AND HEMOGLOBIN READINGS, IN SOME CASES OF LOW BLOOD-PRESSURE

Initials.	Blood-pressure.		Red counts (in millions).		Hematocrit.		Hemoglobin.	
	Diastolic.	Systolic.	Venous.	Capillary.	Venous.	Capillary.	Venous.	Capillary.
P. K.	34	52	3.8	5.6				
A. S.	38	62	4.5	6.4	30	41		
E. G.	40	64	6.2	8.5	30	47	88	113
F. H.	(near death)		4.0	6.0	31	43		
D. H.	48	64	4.2	5.5	37	41	80	95
S. D.	48	72	4.7	5.3	30	35	75	84
W. W. T.	(irreg.)	50	5.3	6.4	..	..	92	98
W. C.	58	76	4.5	5.5				
S. F. S.	58	80	4.9	5.3				
T. R.	70	92	5.2	5.6	39	44	107	111
J. H. C.	80	102	5.8	6.9	41	45	95	105

When shock is complicated by hemorrhage the capillary red count may be low, but when compared with the venous red count the discrepancy between the two at once appears, *i. e.*, when hemorrhage complicates shock the blood in the peripheral capillaries contains relatively more corpuscles in a given volume than in the veins, although in both the number is reduced

As a man in shock improves there is a gradual fall in the capillary concentration to normal or below. In some instances the return has occurred on the second day, and in others it is not complete for three or four days.

The concentration of capillary blood has been observed when blood was removed from the capillaries of the finger-tips, the toes, and the lips; in other words, it is seen in samples taken from widely separated regions. The venous blood was taken from an elbow vein.

Sweating is one of the most uniform features of shock. It is seen shortly after severe wounds and may be the source of more complaint than the wounds themselves.[1] When shocked men are operated upon the sweating may be increased to an almost incredible degree. During an operation the depressions about the eyes have been known to fill with pools of sweat two or three times, while the clothing became drenched with perspiration.

Thirst.—Associated with hemorrhage and lessened blood flow is an insatiable thirst. Unfortunately, the taking of fluid by mouth is practically invariably followed, more or less promptly in case of severe shock, by vomiting, and the patient's condition is made worse instead of better.

The Concomitant Variations of the Degree of Shock and Body Temperature.—It has long been observed in warfare, and the observation has been repeatedly confirmed in the last four years, that shock cases are more frequent and more severe during cold weather, especially during cold, wet weather, than during warm weather. When the shocked man is first brought under careful observation he is likely to have a buccal temperature of 94° or 95° F., or even as low as 89° F. The skin is cold and clammy. Thermometric observations on deep muscle freshly exposed during operation shows that these regions likewise have a temperature below normal.

The improvement of the shocked man on being warmed is confirmatory of the relation between the degree of shock and body temperature.[1] When heat is applied to a man in shock there may be in the course of one-half or three-quarters of an hour a remarkable rise of blood-pressure and general improvement of his appearance. Probably no factor in the treatment of shock is better established than warmth as a means of improving the clinical condition.

Reduction of the Alkali Reserve.—The protection of the body from a dangerous change toward acidulation of the blood lies in the sodium bicarbonate of the plasma. The Van Slyke method of determining the plasma bicarbonate offers a simple means of ascertaining whether non-volatile acid has been unduly developed, and by uniting with the sodium and driving off the CO_2 has diminished this "buffer" salt. Normally in man the amount of CO_2 derivable from the plasma after it has been exposed to the CO_2 tension of alveolar air is above 50 or 55 volumes per cent. A reduction of the CO_2 capacity below 50 or 55 volumes per cent. is commonly defined as "acidosis," but this term must not be regarded as implying an acid condition in the blood.

In 47 determinations of the CO_2 capacity in cases of low blood-pressure at Béthune the following figures were obtained[3]:

TABLE III

Number of cases.	CO_2 capacity (volumes per cent.).
7	50–59 (average 53)
26	40–49 (average 44)
8	30–39 (average 35)
6	20–29 (average 24)

From the foregoing table it is clear that though acidosis is not necessarily present in conditions clinically diagnosed as shock, in the majority of instances it does exist and may be extreme. In the cases under consideration no observations were made on the H-ion concentration of the blood. This concentration is not, however, much increased if the alkali reserve is reduced only slightly below normal. In certain cases of excessive acidosis, however, the hyperactivity of the respiratory center indicated a markedly increased hydrogen-ion concentration.

Correspondence Between the Degree of Acidosis and the Degree of Lowering of Blood-pressure.—In general, the lower the blood-pressure, the lower the alkali reserve, that is, the greater the acidosis. This relation is illustrated in the following figures[3]:

CO_2 capacity (volumes per cent.).	Mean arterial pressure.
50–59 (average 53)	69 mm. Hg.
40–49 (average 44)	61 mm. Hg.
30–39 (average 35)	59 mm. Hg.
20–29 (average 24)	49 mm. Hg.

It is noteworthy that in 40 of the 47 cases the mean blood-pressure was below 60 mm. Hg.; that in all these cases there was a CO_2 capacity less than 50 volumes per cent., *i. e.*, a condition of acidosis; and that as the average CO_2 capacity was low, the average mean pressure was likewise low. A charting of the records of systolic and diastolic blood-pressure in 35 cases, arranged in the order of decreasing CO_2 capacity, revealed a rough correspondence between the lowering of the blood-pressure and the lowering of the alkali reserve.[3]

This acidosis, or reduction of the alkali reserve below the normal, differs from the temporary acidosis which may occur acutely after a quick run or other sharp exercise, in that it is due to a process which may have been going on for hours. The process, furthermore, is a progressive one. Observation made shortly after wounding and again five hours later, with no corrective treatment meanwhile, showed that the CO_2 capacity fell considerably during the interval.

Damage to Control of the Circulation.—If a low blood-pressure persists for a long period, damage is done to the factors controlling the circulation, such that no remedial measures are effective. The *time* element thus becomes fundamentally important. This observation has been confirmed in numerous instances by medical officers who have been successful in treating cases of shock and hemorrhage shortly after the wounding, and have had failure and discouragement in dealing with similar cases a considerable period after the wounding. Other factors than the lapse of time may naturally play a rôle in damaging the wounded man. In warfare, for example, there may be, besides the lapse of time, a prolonged carry over rough roads and exposure to cold in ambulances. That these factors are not essential elements, however, is proved experimentally, for in artificial shock in animals prolonged low blood-pressure in itself results in changes which do not permit any persistent elevation of blood-pressure, whatever the mode of treatment may be.

A Marked Sensitiveness of Shocked Men to Ether or Chloroform Anesthesia.—The effect of chloroform in lowering the blood-pressure in shock cases with the pressure already low has been emphasized by Marshall. He observed a fall of blood-pressure, likewise, after ether anesthesia. In a series of shock cases studied at Béthune a fall was observed during the course of operation under ether anesthesia. The following figures give the systolic and diastolic blood-pressure before and after operation, together with the changes in the CO_2 capacity[3]:

TABLE IV

TESTS AFTER OPERATION UNDER ETHER IN CASES WITH ACIDOSIS AND LOW BLOOD-PRESSURE

Duration of operation, minutes.	Carbon dioxid capacity.		Blood-pressure.	
	Before operation, per cent.	After operation, per cent.	Before operation, mm. Hg.	After operation, mm. Hg.
75	58	46	82–58	58–36
40	58	46	88–62	74–42
60	56	40	98–80	64–48
45	50	44	90–26	64–46
45	47	40	102–80	50–28
70	41	28	76–46	
Averages...56	52	41	89–65	62–40

From the foregoing figures it is obvious that the condition of the patients, which was precarious at the time operation was begun, became extremely serious through the further reduction of blood-pressure. This ominous sinking of the pressure is a source of great peril in dealing surgically with conditions of shock.

Tolerance of Nitrous Oxid and Oxygen as an Anesthetic.—Marshall[6] has testified that anesthesia with nitrous oxid and oxygen is especially to be recommended in operating on men in shock, and Crile and Lower[7] have also stated that this anesthetic is less likely to increase shock than ether. Though nitrous oxid and oxygen may be employed in shock cases without fall of blood-pressure, a fall is not necessarily precluded, as is shown by the following 3 cases:

TABLE V

Duration of operation, minutes.	Carbon dioxid capacity.		Blood-pressure.	
	Before operation, per cent.	After operation, per cent.	Before operation, mm. Hg.	After operation, mm. Hg.
20	49	40	76–58	
60	46	38	76–36	68–28
50	46	27	84–60	58–36

No matter what the anesthetic, an essential precaution for the anesthetist, as will be clear on further discussion, is the avoidance of any

interference with the oxygen supply—*i. e., the avoidance of cyanosis.* The lowering of pressure when nitrous oxid and oxygen have been used may be due largely to carelessness in this regard.

That the fall of pressure as a consequence of ether is not due to lack of oxygen has been shown by use of oxygen as a means of vaporizing the ether in the Shipway apparatus, with the result that the fall occurred just as in other cases when air was employed.

EXPLANATION OF PERTINENT FACTS

The complexity of the state of shock and its modification in natural circumstances by hemorrhage and infection have already been emphasized. Under such confusing conditions it is difficult to obtain satisfactory explanation for observed phenomena without resort to experimental analysis. Shock is a state in which experimental analysis is eminently necessary. In order to account for the foregoing facts, therefore, experimentation on animals has been resorted to. In the discussion of the several points above mentioned reference will be made not only to personal work but also to the work of other observers.

Persistent Low Arterial Pressure.—Low arterial pressure might be due to cardiac weakness, to loss of vasoconstrictor tone, or to a diminished volume of blood for the heart to pump.

Experiments prove that the low pressure of shock is not due to cardiac weakness, at least in the early stages. The proof is supplied by suddenly raising arterial pressure by injection of adrenalin or by cerebral compression.[8] In spite of high pressure rapidly developed, the heart continues to contract without embarrassment. A persistent pressure below 80 mm. Hg. will diminish the efficacy of the heart muscle, so that in time this organ as well as other organs will suffer. Thereupon the cardiac factor becomes important.

The low pressure is not due primarily to lack of vasoconstrictor tone.[9] Clinical and experimental evidence proves that when bodily conditions tend to lessen the blood flow to the vasoconstrictor center, it first reacts by producing an increased contraction of peripheral arterioles. In shock as well as in hemorrhage the early stages may be associated with vasoconstriction (and a thready pulse), though the blood-pressure is falling. Thus in a rabbit in shock, with the cervical sympathetic nerve trunk severed on one side, raising the blood-pressure by aortic compression results in a flushing of the denervated area, but not of the area still connected with the medulla.[10]

The low pressure is explicable as a consequence of blood being reduced in volume; either its plasma extravasated into tissue spaces, or the blood as a whole stagnant in some part of the vascular system, a condition which has been designated "exemia."[11] It has been generally assumed that this exemic blood accumulates in the splanchnic area, but the testimony of surgeons who have had to open the abdominal cavity in hundreds of shock cases is that the exemic blood is not in the abdominal veins. Also it is not in the arteries, for in that case, under conditions just stated, arterial pressure would not be low.

Reduction of Blood Volume.—The accounting for reduction of blood volume in shock remains as one of the central problems to be settled. The reduction is seen in cases of shock, according to Keith, when there is no evidence of marked hemorrhage. Injury to capillary walls is known to make them more permeable to the passage of fluid into tissue spaces. In this connection the work of Dale[12] is suggestive. He has shown that when the substance, histamin, which is found in body tissues, is injected in extremely minute quantities—a few milligrams in the cat—it will induce a shock blood-pressure accompanied by reduction of blood volume and concentration of the blood, a result explicable as due to loss of plasma through injured capillary walls.

It is obvious that profuse sweating would permanently carry away from the body fluid which might be needed for maintenance of blood volume. The sweating which occurs after severe wounds may be an important factor in lessening the tissue fluids and in preventing restoration of normal circulation. The thirst which torments shocked men is evidence of the lack of fluid in the body.

The suggestion has been offered that the lessened volume output from the heart results from fat emboli in the lungs. The evidence that fat emboli accumulate in pulmonary vessels after severe injury, especially to long bones, is conclusive. But that the fat is present in sufficient amount to check the blood flow is highly doubtful. The absence of respiratory distress, pulmonary edema, or prominent veins in nearly all shock cases indicates that pulmonary fat emboli play a minor rôle, if any, in producing shock.

Twenty per cent. of the blood may be removed from an animal with fairly prompt restoration of pressure. And this procedure may later be repeated. There comes a point, however, when even a slight further bleeding breaks the compensation and the pressure falls sharply, not to rise again unless fluid is restored. *This "critical further bleeding" is highly important in dealing with shock cases.*

Concentration of Corpuscles in Capillaries.—The observed concentration of blood in capillaries suggests that the "lost blood" of shock may be largely concentrated and stagnant there. A similar concentration is observed in the capillaries of the intestinal villi in experimental traumatic shock,[20] and, as mentioned above, it is seen also in the shock produced by injection of histamin.

To what degree the concentration is the result of the low pressure itself, and, on the other hand, to what degree it is due to extravasation of lymph from capillaries into tissue spaces, is not yet determined. Clearly, however, any change which results in stagnation of blood in the periphery will lessen the return of blood to the heart, and thereby diminish the volume available for the use of the heart as a pump. The blood-pressure necessarily falls if the volume becomes reduced to a point below the minimal capacity of the constricted arterial system.

Concomitant Variation of the Degree of Shock and the Body Temperature.—The sweating of a wounded man tends to lower his temperature both by evaporation and by favoring more rapid conduc-

tion of heat from the body through wet clothes. If his clothes are already wet, and if after being wounded he has to lie on cold, wet ground, the heat loss is further hastened. The forced inactivity due to the wound lessens compensatory heat production. Also, as blood-pressure falls the heat arising from routine oxidation in the body is greatly reduced. Thus both because of increased heat loss and of decreased heat production the temperature of the shocked man becomes low.

As the temperature of the body falls the rate of metabolic processes falls correspondingly. Naturally, the activity of colder parts is more depressed than that of the less cold. A vicious complex due to cooling and directed toward further diminution of the metabolic rate becomes established.

Increased capillary pressure, lessened conspicuousness of veins, and concentration of blood in capillary areas have all been observed when a part of the body becomes chilled—it becomes "blue with cold." The blood count is higher in a cold than in a corresponding warm part of the skin. Any process leading to stagnation of blood in the capillary region would have its effect augmented, therefore, by the cold that affects both the surface and the deep tissues in shock. Just in so far as the blood flow is checked in capillaries, blood fails to return to the heart, and the exemia and low pressure of shock are augmented.

It appears, therefore, that the variation of shock with body temperature is associated with both the depression of bodily activities and the interference with free capillary circulation, due to cold.

Reduction of the Alkali Reserve.—This may be explained as chiefly due to a too great lessening of the blood flow. When the head of pressure in the arteries is lowered, the volume of blood delivered to the tissues in a given time may be greatly reduced. A fall of pressure from 120 to 80 mm. Hg. may reduce the flow to one-seventh its former speed.[13] The amount of oxygen delivered to the tissues will be likewise much diminished. Any condition limiting sufficiently the oxygen supply to active organs—such as rebreathing expired air, extreme slowing of respiration by morphin, severe hemorrhage, or poisoning with carbon monoxid—will result in the production of lactic acid rather than carbonic acid as a tissue metabolite.[14] Since lactic acid is non-volatile and consequently non-respirable, it accumulates and forms sodium lactate in place of sodium bicarbonate of the plasma—*i. e.*, acidosis develops. There is no evidence that the acidosis, at least in mild form, is in itself harmful. It is, however, the indicator of a really serious danger—that arising from insufficient oxygen supply to the tissues.

Both experiments and clinical observations point to a critical level in a falling blood-pressure, below which the oxygen delivery becomes inadequate. When the output from the heart is lessened by experimentally raising intrapericardial pressure the arterial pressure may be lowered at will. Unless there has been considerable previous hemorrhage, the arterial pressure may be lowered to 80 mm. of Hg. with no change in the alkali reserve; but if lowered to 70, 60, or 50 mm. a marked

fall of the reserve occurs within an hour or even a half hour—the fall varying with the lowness of pressure and with time. Examination of cases studied at Béthune[3] revealed a similar relation between blood-pressure and the alkali reserve below a critical level:

TABLE VI

Systolic blood-pressure.	Average CO_2 capacity volumes, per cent.	Variation.	Number of cases.
96–102	48	40–56	5
90– 92	49	41–58	7
80– 86	49	43–52	5
72– 78	43	30–49	10
62– 68	36	21–42	11
52– 59	24	20–27	5

Since 50 volumes per cent. CO_2 capacity is close to the boundary between normality and acidosis, it is obvious that the maintenance of arterial pressure above 80 mm. causes little alteration in the blood, but that a reduction below that level is likely to be associated with a diminished alkali reserve, more marked the greater the reduction. A systolic pressure of 80 mm. may be regarded, therefore, as being approximately the critical level. Severe hemorrhage will place the level at a higher point.

Damage to Control of the Circulation.—Nerve cells are known to be specially sensitive to lack of oxygen. Certain cells of the cerebral cortex cannot endure total anemia for more than seven or eight minutes without suffering irretrievable alterations. Although cells in other parts of the brain and cord are less sensitive, their existence in total anemia is measured in minutes rather than in hours. When lack of oxygen is not absolute but relative, some adjustment is possible—less activity would involve less demand. The damage done to nervous structure, such as that controlling vasoconstrictor tone, might be expected, therefore, to be gradual.

The observations of Crile that nerve-cells taken from shocked men show chromatolysis have been confirmed by Mott. These changes, however, are not regarded by Mott[15] as indicating a nervous origin of shock, but are interpreted by him as due especially to anoxemia, and possibly also to stress and toxins.

Besides injury to nerve-cells there may be injury to capillary walls from inadequate circulation. Complete absence of flow from an area results after a short time in capillary dilation, greater permeability of the walls, and extravasation of fluid. The experiments of Erlanger and his associates[9] point to similar effects resulting from partial obstruction of the blood flow; for at the time shock pressure first develops, after partial occlusion of the thoracic aorta, for example, vasomotor tone may be above normal. Further, there is evidence that if the circulation is shut off from a considerable part of the body for some time (an hour or more), the return of blood flow in the part sweeps throughout the body material which lowers arterial pressure.[16] Absence of adequate blood-supply, therefore, evokes secondary agents with depressive influence.

A greatly lessened blood flow injures the circulatory apparatus by damaging both the central nervous control, which maintains arterial tone, and also the capillary endothelium. The rate and degree of damage would probably be dependent on the amount and duration of the diminished flow.

In accordance with the foregoing considerations, both clinical and experimental observations prove that if a low blood-pressure has persisted for a sufficiently long period, no remedial measure will cause a permanent rise. Blood transfusion is hardly more effective than injection of salt solution; with each there is only a temporary improvement of circulation; even after a large blood transfusion the blood volume may be only slightly increased and diffused moistness of the tissues points to failure of the capillaries to retain fluid.[4]

Sensitiveness to Ether and Chloroform Anesthesia.—The central and peripheral factors in control of the circulation are probably both involved in the further depression of the shocked man which results from ether or chloroform anesthesia. The vasoconstrictor center, already damaged by lack of oxygen, may suffer still further loss of tone from these depressant drugs, and may fail to compensate for their depressant action on the heart. The blood-pressure consequently drops to a lower level.

Furthermore, Dale[12] has recently brought forward evidence that ether induces changes in capillary walls, so that they more readily become permeable—an effect not observed after nitrous oxid anesthesia. By escape of fluid into tissue spaces the effective volume of circulating blood would be reduced and thus the blood-pressure would drop still more.

Summary.—In a review of the observations on shocked men and the experimental evidence it appears that the central condition is a low blood-pressure due to diminished volume of circulating blood, that this condition is made worse by cold, that if the pressure falls below a critical level the tissues suffer from lack of oxygen, that persistence of this insufficient circulation may induce irremediable damage to the circulatory system, and that in the shock state there is peculiar sensitiveness to ether and chloroform anesthesia. The rational treatment of shock must take into account all these circumstances.

THE TREATMENT OF SHOCK

In treating the shocked or the severely wounded who may pass into shock the *early* use of *simple* measures is of primary importance. These measures will be described in relation to the conditions which have to be met.

Bleeding.—Reference has already been made to the evidence that long exclusion of the circulation from a part will in some manner, when the blood flow is restored, cause a sharp fall of pressure which may pass into shock. Cases have been reported in which removal of a tourniquet long left on a limb has resulted in prompt development of a shock pressure. Avoid altogether, if possible, the use of a tourniquet to

control hemorrhage; if one is absolutely required, place it as distally as conditions permit and remove it as soon as vessels are tied. If it is to be left long in place, note when it was applied.

The suggestion has been offered that if a limb has been so badly mangled that it cannot be saved, a tourniquet set close above the traumatized tissues and left in place *until after operation* will protect the body against absorbed toxic material arising in the wound.[17]

Loss of Body Heat.—The well-established association between shock and low temperature emphasizes conservation of body heat.

In examining an injured man subject him to as little exposure as possible; do not lay bare a new part before covering the part already examined.

If he cannot be placed in bed at once, surround him with blankets. If anything, there is need for *more* blankets *under* the body than over, because the patient's weight lessens in the fabric the air space which checks the passage of heat. By using three blankets, as illustrated in Fig. 89, four layers above and below may be obtained. The feet should be well wrapped in warm covers.

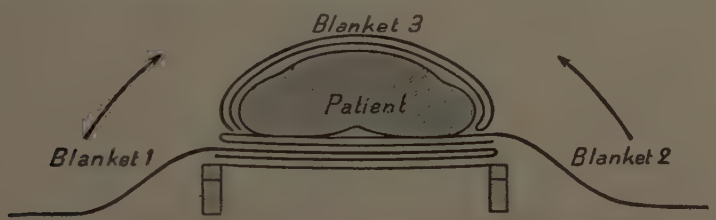

FIG. 89.—METHOD OF FOLDING THREE BLANKETS TO PROVIDE FOUR LAYERS BENEATH AND FOUR ABOVE THE PATIENT.

The free ends of blankets 1 and 2 are folded over the two layers of blanket 3 already in place above him. (From the pamphlet "Traumatic Shock and Hemorrhage," issued from the Division of Surgical Research, Central Medical Department Laboratory, and published by the American Red Cross for the American Expeditionary Forces, France, 1918.)

If the patient is already cold or is likely to lose heat in spite of blanketing, heat may be contributed by means of hot-water bottles. More service is obtained from these bottles by using both sides than by using only one. Also heat passes faster from a warm to a cold object than to a lukewarm object. Accordingly, place one bottle on the abdomen with the hands laid over it. And set a second one between the feet. If more bottles are available, they may be placed between the thighs, and pushed toward the axilla between the arm and chest on each side.

Another mode of contributing heat is by means of hot drinks. If the alimentary tract has not been injured, and if the fluid is not vomited, the hot drink is the best method of warming. It satisfies thirst. All the extra heat of the fluid passes to the body. Moreover, the fluid helps to replace a reduced blood volume. Hot tea or coffee are often relished.

A rectangular space the length and width of a stretcher and about 3 feet high, surrounded by blankets and heated by a lamp or oil stove placed on the floor, makes a warm chamber over which stretchers may

be set. In military service this has proved a simple and satisfactory method of warming the wounded or keeping them warm during examination. A number of such chambers may be heated by running a stove-pipe through them from a single oil stove and having the pipe perforated in each chamber. In the preliminary examination and dressing wet clothing should be removed, and, if necessary, more blankets added.

If on arrival at the hospital the patient is cold, he should be undressed (with care not to lose more heat) and put in a warm bed. A highly effective means of warming the patient is to set over his body and legs fracture frames, which are covered with blankets, and then to introduce heat into the covered space. A permanent arrangement for this purpose may be made by wiring six or eight electric lights inside the frame. Another device is that of leading from near the floor to the space under the frame an elbowed stove-pipe, using a lamp or alcohol burner on the floor under the pipe as a source of heat.

Care should be exercised not to overdo the heating. The shocked man is suffering from reduced blood volume and should not lose further fluid by sweating. The clinical improvement seen when a wounded man, cold and shocked, is merely put to bed and warmed is often astonishing; a pulse absent at the wrist may return in good volume, and the blood-pressure may rise 30 or 40 mm. within an hour.

Pain and Restlessness.—If a bone has been broken, it should be carefully splinted before moving the patient. The use of the Thomas splint in forward areas is said to have done more than any other agent to reduce the incidence of shock in the British Armies during the past war. Splinting benefits the wounded man both by lessening the occasion for pain and by minimizing further traumatization from the movement of bony fragments.

If the carriage of a shocked man is long and rough, his chances, unless infection is rapidly developing, are improved by stopping occasionally and giving him opportunity to be warmed, rested, and supplied with fluid. Such opportunity is usually offered in warfare at the regimental aid post and the advanced or ambulance dressing stations, before the hospital is reached. The eagerness of the ambulance service to give rapid transportation should not be permitted to interfere with the restoration of a shocked man before he is carried to the next station.

Concerning the use of morphin there have been differences of opinion. It has been advocated to the point at which the respiration sinks to at least 12 per minute.[7] On the other hand, there is expert testimony that the severely wounded who have been deeply morphinized recover unsatisfactorily from operation.[6] The object to be sought in giving morphin is to blunt the feeling of pain, especially during a rough carry, and to reduce or abolish the restlessness which is wasting the patient's energy. Under morphin the blood-pressure may be lowered further without producing acidosis than under normal conditions—an observation which suggests that morphin lessens metabolism when the

oxygen needed for its maintenance is insufficient. The drug should be given, therefore, until the patient is comfortable and quiet. In some cases $\frac{1}{4}$ grain may be sufficient; in others $\frac{1}{2}$ grain may be needed. The dose should be repeated if necessary.

The Low Blood-pressure.—If simple measures, such as warmth, rest, and fluid by mouth, do not raise the systolic pressure within an hour to at least 80 mm. (if there has been much hemorrhage the pressure should be higher, 90 mm. or more), other means should be used to raise it. Evidence of extensive hemorrhage, associated with a very low pressure, would warrant radical interference as soon as the patient is warmed. The decisively harmful effect of prolonged insufficient blood flow should always be kept in mind.

To rationalize the treatment of low pressure the facts previously developed must be remembered, and also the fact that the blood is serviceable to the tissues in the capillary region only. The primary cause of the low pressure is a diminished volume of blood in circulation. By giving adrenalin or pituitrin the arterial pressure may, to be sure, be temporarily raised. This results from increase of peripheral resistance through *constriction of the arterioles*. In consequence, the blood is dammed in the arteries. There is no evidence that the blood flow is thereby improved in the *capillaries*, except briefly in the brain and heart after adrenalin. The rise of blood-pressure after use of vasoconstrictor drugs in shock is, therefore, quite misleading. Merely a higher arterial pressure is not the desideratum, but a higher pressure with an *improved capillary circulation* in consequence. This can be obtained, when a diminished volume-flow is the cause of low pressure, only by increase of the volume-flow. In British and American services the use of stimulant and vasoconstrictor drugs practically disappeared during the course of the recent war.

To increase the reduced blood volume the simplest means, if the situation is not urgent, is to give fluids by mouth. Unfortunately, vomiting is likely to occur. In that event fluid may be given by rectum. In one case, by forcing fluids through the alimentary tract, Robertson and Bock[18] increased the blood volume nearly 1400 c.c. in twenty-four hours.

It has not yet been proved that normal salt solution injected intravenously has more than a temporary effect. The fluid promptly passes through capillary walls into tissue spaces and within a brief period the pressure is as low as before, if not lower. Favorable results have been claimed for normal salt solution given subcutaneously, but not on the basis of critical observation. In human cases, with low pressure and sluggish blood flow, the injected fluid has been found *postmortem* spread in the fascia of the region of injection. And careful following of the hemoglobin percentage after subcutaneous injection has not revealed that dilution of the blood which would appear if the solution entered or was retained in the vascular system.

An indifferent fluid, which on being intravenously injected remains in the blood-vessels, would raise a low pressure through increase of

volume; and by increasing the rate of flow it would increase the utiliza- has advocated the addition of a colloid, 6 per cent. pure pearls of gum tion of the red corpuscles as oxygen carriers. For this purpose Bayliss[19] acacia, to normal salt solution. This "gum-salt" solution has the same viscosity and the same osmotic pressure as blood-plasma, it is not altered by a sterilizing heat, and does not escape through capillary walls as simple salt solution does. Under experimental conditions it has been used to replace as much as 75 per cent. of the estimated blood volume, with survival of the animal and with no deleterious effects. Clinical reports of its use in early stages after hemorrhage and shock have been favorable; in late stages it has been reported as having no value or as causing severe reactions ("chills"), followed by low pressure and death. *Postmortem* examination may then show escaped fluid in the tissues—a result which is attributable to pathologically permeable capillaries.

Recently hypertonic gum acacia (25 per cent.) in 18 per cent. glucose solution, injected very slowly, has been advocated by Erlanger and Gasser,[20] who have reported favorable results from it in experimental and clinical cases. The object of the hypertonicity is to draw back fluid which has escaped into the tissues.

The merit and limitation of gum-salt solution may be regarded as still not determined except in late shock, when it has proved definitely useless. At best it is a substitute for blood. And though there are late cases in which transfused blood has been as ineffective as gum-salt solution, there are other cases reported in which blood has sustained a satisfactory pressure after gum-salt solution had failed.

The transfusion of blood in cases of shock has been proved highly valuable beyond question by the experience during the war. As the methods of matching blood, the technic of transfusion, and the absence of harm to donors become better known, blood transfusion in shock and hemorrhage seems certain to be the method of choice for restoring a low blood volume. (See chapter on Transfusion.)

Whatever solution may be injected, the following precautions should be regarded: (*a*) 500 c.c. may be given at first and repeated, if necessary; (*b*) it should be given at body temperature or slightly above; (*c*) it should be introduced slowly, to avoid embarrassing the right heart by an excess volume; (*d*) it should be checked or stopped if any harmful effects are observed; and (*e*) it should be given *as soon as possible* after simpler means of raising blood-pressure have proved ineffective.

Operation on a man who is in shock, or who has been in shock for a considerable period, is likely to be hazardous because the already low blood-pressure may be seriously reduced in consequence of the operative procedures. A number of conditions contribute to this danger, some of which can be avoided.

Heat.—Continue during operation every effort previously employed to prevent heat loss. Scrupulously avoid needless exposure of the body. Do not permit the skin and protective coverings to remain wet. Wash out cavities and wounds with warm solutions only. A warmed operating table is desirable.

Bleeding.—When blood volume has been reduced, a slight hemorrhage, quite without effect under ordinary conditions, may cause a calamitous fall of pressure. Special care must be exercised during operation in shock cases not to lose a drop more blood than actually must be lost.

Manipulations.—After laparotomy on a man who is or has been in shock a turn of the body laterally causes a sharp drop in blood-pressure.[6] If the back is wounded attend to that before opening the abdomen. Apply binders or many-tailed bandages by lifting the body, not by turning it from side to side.

Abdominal and thoracic viscera should not be exposed or pulled upon more than is absolutely required by circumstances. Handle all tissues with extreme gentleness.

Time of Operation.—The testimony has been general that it is best to give a shocked man time to recover both from his low blood-pressure and from the effects of the low pressure before operating. A number of conditions modify this rule and involve special precautions.

In case of concealed hemorrhage accompanying and augmenting shock it is necessary to operate to stop bleeding. Again, when there is rapidly spreading infection (*e. g.*, with gas bacilli), operation may seem wise before full recovery has occurred. Under these circumstances preparations should be made to limit the operative procedure to essentials and to complete it as soon as possible. Lest the blood-pressure fall seriously during operation arrangements should be made beforehand for prompt transfusion or infusion.

Although delayed operation has been generally accepted as the approved course in shock, it is proper to note that a number of good observers[21] have been impressed by the striking and fairly prompt improvement which follows removal of a mangled limb or excision of mashed and gas-infected muscle. Santy,[22] who in 1917 observed 340 cases of non-transportable wounded, found that in 79 cases, in which the time between being wounded and receiving surgical treatment was known, the mortality was only 11 per cent. with surgical treatment in the first three hours; it rose to 34 per cent. when there was delay between three and six hours (though infection is not marked until after six hours); and was 75 per cent. in the eighth and ninth hours. These observations are mentioned as suggesting a point of view regarding the surgical treatment of shock which deserves careful consideration.

Anesthesia.—The sensitiveness of shocked men to ether and chloroform anesthesia and their tolerance of nitrous oxid and oxygen as an anesthetic have previously been emphasized. Chloroform and ethyl chlorid should not be used except as a last resort. If ether must be used, the head of arterial pressure should be maintained by transfusion, in order to avoid the effects of a serious fall of pressure which is likely to ensue.

Clinical and experimental observations have shown that if anesthesia with nitrous oxid and oxygen is properly produced a shock blood-pressure need not be lowered at all during the course of operation.

But high ratios of nitrous oxid to oxygen (*e. g.*, 6, 5 or 4 to 1) will cause quite as sharp a drop of pressure as ether itself. A ratio of 3 parts nitrous oxid to 1 of oxygen will produce satisfactory analgesia if expertly administered and if preceded by morphin. The surgeon must adapt his technic to this light anesthesia, and to possible absence of complete relaxation, by patience and gentleness and by a larger operative incision when necessary.

At all times avoid deep anesthesia and cyanosis. In an organism suffering from want of oxygen, shutting down on the oxygen supply to the lungs is certain to do harm. Cyanosis during operation causes a shocked man to lose ground which it may be extremely hard to recover.

After-care.—It should be remembered always that the patient who has been in shock and resuscitated, and then operated upon, is in a precarious condition. He should be carefully watched for unfavorable developments. Rest, warmth, and fluid by mouth or rectum should be continued. The same principles should govern the treatment of a return of the shock state as were applicable before operation.

Important experimental work directed toward elucidating the nature of shock has been carried on during the past two years by members of the special committees on shock of the Medical Research Committee in England and of the National Research Council in the United States, and by individual investigators in France. Because this work has not yet been fully published and because the conclusions to be drawn from it are not yet clearly formulated, it has seemed best to postpone an account of it until later. The reader who may be interested in these experimental investigations will find some of them referred to in the Bibliography at the end of this chapter.

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CHAPTER XII

"TRAUMATIC" HYSTERIA INCLUDING SO-CALLED "SHELL SHOCK"*

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In the interval occurring between the publication of the chapter (XXXIII, Vol. II) on Traumatic Neurasthenia, Traumatic Hysteria, and Traumatic Insanity in 1907 and the appearance of the supplementary chapter (CVIII, Vol. VI) in 1913 a change in the interpretation of the nervous symptoms found in accident cases, generally, was noted. This change was due to an increasing acceptance of the views of Babinski in regard to the origin of hysteric symptoms. Since the writing of the supplementary chapter a still further and more radical change in opinion has taken place.

The expressions "spinal concussion" and "railway spine" have disappeared from medical literature and are no longer heard in the courts. Oppenheim substituted for them the term "traumatic neurosis." Unfortunately, the word "neurosis," vague and indefinite in meaning, failed utterly to convey any conception as to the nature of the condition present. Notwithstanding, the expression "traumatic neurosis" rapidly became the vogue. Soon, however, the hysteric nature of the symptoms became more and more evident, and the expression "traumatic hysteria" came to be used. For a long time the profession were inclined to hedge, with Oppenheim, as to the purely hysteric nature of the symptoms, and such terms as "traumatic neurasthenia" and hybrid expressions, such as "traumatic hysteroneurasthenia," came to be employed, but they finally definitely gave way with our increasing knowledge to the term "traumatic hysteria," and thus medical men gradually came to adopt a position which one of them, Charcot, had long anticipated. The hysteric nature of the traumatic neuroses must now be regarded as definitely and finally established.

Babinski's studies in hysteria threw an additional flood of light upon the subject. As pointed out in Vol. VI, p. 254, Babinski showed that the symptoms were frequently developed as a result of the medical examination. In testing 100 consecutive cases of hysteria not previously examined by physicians for hemianesthesia, and being careful to avoid making any suggestion, he failed to elicit the symptom in a single case. Again, the hemianesthesia is usually developed upon the left side of the patient's body, left side of the face, and left extremities. Babinski pointed out that the physician, being usually right-handed,

* Supplementary to Chapter XXXIII, Vol. II, p. 759, and ,Chapter CVIII, Vol. VI, p. 254.

holds the camel's-hair brush, pin, or esthesiometer in his right hand, and, facing his patient, naturally tests the left side of the patient first, thus suggesting the very hemianesthesia he is trying to discover.

Finally, another point of fundamental importance now becomes evident. If the physician tests a healthy or normal individual for hemianesthesia, making at the same time free use of suggestion both direct and indirect, he invariably fails to develop the symptom. In other words, the fact whether a hemianesthesia is or is not developed depends upon the previous existence of hysteria in the individual. That this truth applies to all of the so-called stigmata of hysteria need not be stated; all are the result of suggestion either of medical or other source.

Further, when a given symptom is studied the fact that it is not real or genuine is usually capable of ready and convincing proof. Recurring to the symptom of anesthesia, it is noteworthy, first, that unless the patient has been previously examined by a physician, and more especially by a neurologist, he does not, when he presents himself to the examiner, complain of loss of sensation. Before the examination he has no knowledge of its existence, and even after it has been elicited he does not conduct himself either during the remainder of the examination or subsequently as though the part in question were really anesthetic. Immediately after an examination a patient who has been partially disrobed will not infrequently use a supposedly anesthetic hand in dressing himself in a most natural manner and apparently without the slightest impediment. Buttons, hooks, pins are adjusted without hesitation, as though the patient had full knowledge of the position and physical qualities of these objects through touch. Spontaneously, too, the patient may, without thinking, perform various acts which are incompatible with true sensory loss. Thus, a patient in whom an anesthesia has been supposedly established may, when her case is not under discussion, pick up a kitten and stroke its fur or may possibly resume an interrupted piece of sewing, knitting, or fancy work. Again, the hysteric anesthesia is never the seat of injury as is the case in a real anesthesia. The patient never burns or bruises the anesthetic part as is so frequently the case, for instance, in syringomyelia.

Finally, that the supposed sensory loss does not really exist is definitely proved by the following facts: Quite frequently during an examination painful stigmata—painful superficial areas—are developed in various situations; usually beneath the breast, over the groin, or over the back. It is an astonishing and conclusive fact that commonly after a hemianesthesia has made its appearance, such painful areas can be developed on the very side in which loss of sensation has just supposedly been demonstrated.

What is true of the sensory losses of hysteria is true also of all the other symptoms, whether these consist of palsies, of symptoms referable to the various organs, or to the general conduct or attitude of the patient.

The facts in our possession at the present day justify no other con-

clusion than that hysteria is an affection which is innate in the individual. It is characterized by a feebleness of resistance to impressions of all kinds, by a pathologic susceptibility to suggestion, and by a more or less marked emotional instability. The hysteric person is more readily frightened than the normal person, and the manifestations of the fright are commonly out of all proportion to its cause. The special symptoms of hysteria are evoked by suggestion, fright, or other emotional factors. Trauma unconnected with fright plays no rôle. It is a noteworthy fact that trauma occurring during sleep or during surgical anesthesia is never followed by hysteria. Again, persons injured during sports, in gymnastic exercises, in football, never develop "traumatic hysteria." This is true also of accidents to railway employees, who form a notable contrast in this respect to passengers.

The phenomena presented by a given case of hysteria persist so long as the suggestion which called them forth persists. This fact has a special application to the hysteria observed in accident cases. A hysteric woman may have a fall, and subsequently, because of the fright and the suggestion of injury into which the fright resolves itself, may present a hysteric paroxysm. Most frequently crass hysteric phenomena do not ensue immediately; not, indeed, until some time has elapsed; that is, time is usually necessary for the suggestion of injury to become operative. In hysteria evoked by accident not involving litigation the interval is usually short and the symptoms rarely pronounced. The latter, as a rule, fade and disappear spontaneously or readily under the suggestion of treatment. However, as we all know, if the attitude of the friends and others, and especially of the physician, be such as to confirm the belief in injury, and if, in addition, the patient be made the subject of sympathy and coddling care, the duration of the symptoms may be very much prolonged. In the vast majority of cases, however, in which there is no element of compensation the symptoms rapidly subside and the patient resumes his usual condition.

The presence of the element of compensation it need hardly be stated introduces a factor which influences the development, the degree, and the persistence of the symptoms. Not infrequently some time—a period of ten days, two weeks or longer—elapses before the maximum development of symptoms is reached. It is just in proportion that the importance of the symptoms to the claim for compensation is realized that the symptoms develop and become pronounced. The symptoms and the expectations of the amount of compensation grow and expand together.*

SO-CALLED "SHELL SHOCK"

When we turn our attention to the hysteria of so-called shell shock a parallel series of facts present themselves: (1) as to the pre-existing neuropathy; (2) as to the occurrences which evoke the symptoms, and (3) as to the causes which lead to the persistence of the symptoms.

* For details the reader is referred to Hysteria and Accident Compensation, by F. X. Dercum, The Geo. T. Bisel Co., Philadelphia, 1916.

The pre-existing neuropathy has been emphasized by Osler, Forsyth, Mott, Adrian and Yealland, Wolfsohn, and others. In Viets' excellent digest of the English literature of shell shock the facts are summarized by the statement that "it has been found in a large majority of cases of shell shock that the patients have a neuropathic tendency or inheritance." Viets quotes Forsyth as saying: "In all cases coming under the writer's notice with symptoms which were more than mild or transitory a history of some earlier nervous troubles, slight or severe, was forthcoming," and further, that "the occurrence of a definite neurosis is to be looked for only in psychopathic individuals, the onset representing the collapse of what is already unsound." Again, Adrian and Yealland, in a report on 250 cases, say: "There are certain mental abnormalities which are present to some extent in nearly every patient. The majority of patients are below the average normal intelligence as judged by the Binet-Simon scale, and others who are more highly equipped prove to have an unstable history either personally or in the family." Finally, Viets quotes Mott as saying: "Of even greater importance than the extrinsic conditions in the causation of military unfitness from exposure to shell fire are the intrinsic conditions, for if there is an inborn timorous or neurotic disposition, or an inborn or acquired neuropathic or psychopathic taint, causing a *locus minoris resistentiæ* in the central nervous system, it necessarily follows that such a one will be unable to stand the terrifying effects of shell fire and the stress of trench warfare."

The same general truth is also recognized by G. Elliott Smith and Pear, who express themselves as follows: "It is thus obvious to anyone who gives the matter any serious consideration that the manifestation of a severe psychical shock must necessarily be determined in a large measure by the nature of the mind on which the injury falls. It would be idle to pretend therefore that, in diagnosis, the story of the patient's past experience can be left out of account, for the manifestation of the injury will obviously depend largely upon the individual patient's 'mental make-up.'"

In his introductory note to Wolfsohn's important paper on the predisposing factors of war psychoneuroses Col. Pearce Bailey gives a brief summary of the reports of 8 medical officers, detailed for study in shell shock hospitals in England during the summer and fall of 1917, and, among other things, states that in respect to etiology these officers all lay much stress on constitutional predisposition. Wolfsohn's conclusions as to this point are extremely interesting. He studied 100 cases of war psychoneuroses and found that the vast majority were among soldiers who had a neuropathic or psychopathic soil. In 74 per cent. of these cases a family history of neurotic or psychotic stigmata, including insanity, epilepsy, alcoholism and nervousness, was obtained, while a previous neuropathic constitution in the patient himself was present in 72 per cent.

When we turn our attention to the occurrences which evoke the symptoms we again find that they do not differ in kind from those met

with in railroad accidents. The intense emotional strain, severe fright, as well as the vivid suggestion of injury are equally present in both instances. These are facts so evident that it seems hardly necessary to emphasize them. Further, the parallelism between shell shock and railroad accident cases becomes more and more apparent the more we study the subject. Ames, for instance, states that "war shock never develops in a sleeping man when a shell bursts near him," a fact which is equally true of persons asleep at the time of railroad accidents. He tells us further that "crack regiments have fewer men coming down with war shock, as do old regiments with long traditions of pride." No doubt the reason is that in such regiments neuropathic individuals have been largely eliminated.

Other facts in close accord with our knowledge of the hysteria of civil life are also presented by shell shock. Thus Ames states that throughout the war it has been a matter of continuous comment that *wounded men* did not have war shock, a fact in keeping with the absence of hysteric symptoms in the physical injuries of railroad accidents. Again, Ames states that the large percentage of war shock cases have their onset some time after the shock, some of the men being for several days without any symptoms at all. Here we have again an exact parallel of the fact observed in railroad cases, namely, that time is necessary for the suggestion of injury to become operative. Other facts are equally significant; for example, Ames tells us that among officers there is a relatively smaller percentage than among privates. MacCurdy, in his discussion of Ames' paper, stated among other things that the paraplegias, the blindness, the mutism, tics, etc., occur preponderately among the private soldiers, and further said that this corresponds to the experience in civil life, where functional palsies are rarely met with outside of dispensary practice. When officers do suffer, it would appear that they present symptoms largely psychic in nature, just as do the hysterics met with in the upper classes and upper middle classes in civil life.

Many other facts suggestive of the psychology of shell shock might be added. For instance, *prisoners of war* do not have shell shock; no doubt partly because to a hysteric subject to be a prisoner of war implies safety to life and limb, immunity from the dangers of battle; at least for the time being. Again, *wounded men*, as already stated, do not have shell shock; a wound in a hysteric subject implies removal from the front; dismissal, temporary or permanent. Gaupp, quoted by Elliot Smith and Pear, states, in discussing cases in which nervous trouble, uncontrollable in nature and intensity, had led to the patients being kept in German hospitals for months, that it was sometimes found that the mental foundation which was a causal factor of these troubles was a more or less conscious anxiety concerning the possibility of a return to the front. In short, we have here a series of facts more or less parallel to those noted in the accident cases of civil life in which both the evoking of the symptoms and their persistence are dependent on suggestions. These suggestions are often doubtless subconscious in

their operation, at least they are not frankly admitted by the individual. Finally, the causes cease to be operative the moment that the suggestion disappears, as witness the practically immediate recovery of the hysteric claimants for damages when litigation ceases and the claims have been disposed of.

Without further consideration, let us turn our attention next to the important question of prevention. Can war shock be prevented, or, if it cannot be prevented, can it be minimized? Obviously, there is only one remedy, and that is as rigid an exclusion as possible of neurotic and neuropathic individuals from the ranks. Others, for example, Osler and Salmon, have expressed themselves emphatically on this point. It is the duty of the medical examining boards and especially of the medical advisory boards to eliminate such persons with the utmost care. Surely we should profit by the experience of the countries that preceded us in the war, notably England, and as far as possible prevent the accession to the ranks of material not only worthless for actual fighting, but which greatly reduces the efficiency of the army and clogs and clutters its hospitals.

Next, what shall we say as to the treatment of cases after they have occurred? In considering this question it is most interesting to note the change which took place in Paris previous to the war both in the management of hysteria and in the results achieved. This change followed Babinski's remarkable and convincing interpretation of the symptoms. The patients now ceased to be made the objects of suggestive medical studies, of interest, and of special care; they no longer occupied the center of the stage; convulsions, gross palsies, or other manifestations were alike ignored as though they had no existence, and the inevitable result followed. In the summer of 1913 Babinski stated to me that major hysteria had disappeared from the hospitals of Paris. This is a remarkable fact and one which must influence our attitude toward and our treatment of the hysterias of war.

The attitude adopted in France is most interesting and significant and may be properly regarded as just and final.

At a joint meeting of the Neurological Society of Paris and the chiefs of the military neurologic and psychiatric centers, on December 15, 1916 a discussion was held on the relation of the neuroses and psychoses of war to dismissal from the service, to unfitness for service, and to gratuities. The discussion was most elaborate and detailed. Those participating in the part on the neuroses were Grasset, Babinski, Léri, Souques, Henry Meige, Laignel-Lavastine, Dide, Chiray, and others. After its completion the following conclusions were adopted:

1. For symptoms purely hysteric (pithiatic) neither dismissal from the service nor gratuities.

2. For cases in which hysteric (pithiatic) symptoms are associated with organic affections, either physiopathic or mental, no account is to be taken of the hysteric manifestations in the evaluation of the degree of the incapacity.

3. For physiopathic disturbances (nervous disturbances termed

"reflex") consecutive to traumatism of war and refractory to a prolonged treatment: auxiliary service or temporary dismissal with gratuity in amount proportioned to the functional interference.

4. For neurasthenic states, well marked, even without objective or mental disturbance; most often auxiliary service, exceptionally temporary dismissal with or without gratuities.

These conclusions need no comment and no explanation; least of all do they need a defense.

The most potent remedy for shell shock is, as has already been emphasized, its prevention by the exclusion of individuals unfit for service. The most satisfactory plan of dealing with it after it has occurred would seem to be that instituted by the English. At first the cases were sent from the evacuation hospitals in France to special hospitals in England. Here general physiologic measures, virtually a rest treatment, with psychotherapy, occupation, and what not were instituted, but with results that were only partially successful, and even when patients were supposed to have been restored they not infrequently relapsed on the way back to the front. Subsequently, as recounted by Bailey, general methods of treatment, such as diversional occupation, extra diet and entertainments, were replaced by more rapid and more satisfactory procedures. Electricity given for psychic effect was found to be a valuable agent. It was accompanied by strong persuasion. Cases were reported cured in this way in a few hours which had formerly lasted for months.

Nothing more potently illustrates the truth concerning the nature of shell shock than the statement of Surgeon-general Ireland before the Senate military committee on December 13, 1918: "More than 2000 American soldiers in France suffering from shell shock were cured by the news of the signing of the armistice." Of 2300 shell shock patients, the General said, all except about 300 were well almost immediately. "It was the greatest experience in psychotherapeutics known."

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CHAPTER XIII

TRANSFUSION OF BLOOD AND ITS SUBSTITUTES

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The war just ended is the first in which the transfusion of blood has found a place as a practical life-saving measure, and as a result another important chapter has been added to war surgery. In the prewar days European surgeons had scarcely used transfusion in their civil practice, and the onset of hostilities found them unfamiliar with transfusion problems and a practical knowledge of its technic. Von Ziemssen's method of transfusion by means of syringes and needles, published in 1892, had failed to establish itself and had apparently been forgotten.

It remained, however, for two American surgeons, Carrel and Crile, to bring the operation again to the foreground, the former by his finished work in suturing of blood-vessels, and the latter by devising an apparatus and a technic which made transfusion available and possible to all surgeons. To these two men, therefore, humanity owes much. Many Europeans took notice of Crile's contribution, but practically no one abroad had seriously followed America's lead.

Here at home, upon the other hand, the whole subject of transfusion was given a tremendous impetus with Elsberg, Levin, Brewer, Hartwell, Ottenberg, and many others keenly alive to the subject, with a resulting study of its various aspects, and the invention of numerous forms of apparatus to easily accomplish the transfer of blood. About this time Moss and Landsteiner, each working independently of the other, had clarified the question of blood reactions by discovering the existence of the various blood groups. This work was far reaching in its practical application, for without it much of the present advance in transfusion would have been impossible.

Late in 1917, before any active participation by the American Army, the Department of Clinical Surgery took up the question of transfusion. Early in January, 1918, a Committee for the United States Army was appointed to consider in all its aspects transfusion in the war zone, with the object of adopting every practical means for making the procedure useful and readily available. This committee immediately began its work, and in March had published a report of information and instruction upon transfusion which was available for army surgeons. They had also provided an apparatus for use in the advanced and rear hospitals of the army, and had established a real liaison with the Department of Laboratories, where courses of instruction were

arranged for and laboratory supplies were to be continually furnished to the workers in the field.

What are the practical problems of transfusion in war? These may be enumerated as follows:

1. The general problem.
2. Organization.
3. Diagnosis of acute anemia following hemorrhage and indications for transfusion.
4. Substitutes for blood.
5. Technic to be adopted, including the necessary apparatus.
6. Selection of donors and supply of donors.
7. Blood reactions of the recipient following citrated transfusion.
8. Results.
9. Conclusions.

I. THE GENERAL PROBLEM

The surgeon believes that a soldier suffering from the effects of serious hemorrhage should have a chance for his life. With the anemia following a severe acute hemorrhage it is obvious that the vast majority of patients will be in the very advanced area, and as help must reach them within a few hours, transfusion must be done far forward, in an advanced hospital. Such a hospital is usually either an advanced triage, a mobile unit for non-transportables, or an evacuation hospital, the latter corresponding to the British C. C. S. Men who have suffered from a severe hemorrhage, particularly those who have been exposed to cold and hunger, cannot be evacuated far to the rear, for they stand transportation poorly, and the vital hours within which they must receive blood are lost. Therefore any plan adopted for transfusion must lend itself to this necessity for forward work.

The base hospitals, though having much less need for transfusion, yet furnish an important field. Many cases suffering from the effects of single or repeated secondary hemorrhages urgently require transfusion. While any technic with which the base surgeon is familiar may properly be made use of here, in general, it may be said that some standardization of apparatus is desirable, from the standpoint of army supplies and the possibility that a surgeon at the base may be detailed for forward work at any time. With the same type of instrument in use in both areas a base surgeon will not be embarrassed in attempting transfusion in an advanced unit.

II. ORGANIZATION

A carefully devised and executed plan must be in hand if transfusion is to be carried out efficiently in a large way in any army.

1. There should be a small committee to organize the work, at least one member being a laboratory man. This committee should be responsible to the Department of Clinical Surgery.

2. Such a committee ought to furnish for army surgeons a pamphlet of information and instruction upon transfusion, written in terse, clear English.

3. Men of special fitness should be assigned to transfusion work through the co-operation of the department of clinical surgery. If a needling technic is determined upon, those chosen should be, as far as possible, medical men, that surgeons may be spared for other necessary operative work.

4. A short course should be provided at the Department of Laboratories, with provision for the study of apparatus, grouping, and technic, under the supervision of the laboratory member of the committee. A definite relationship between the committee and the Department of Laboratories must be established, for effective work on a large scale must fail unless the committee receives the co-operation of the army laboratory. In the war just ended the Department of Laboratories in the American Army gave its heartiest support to the problem of transfusion.

5. Well-planned laboratory boxes should be supplied containing all the essentials for the laboratory end of transfusion work. Such supply boxes in the American Army included the following:

(1) Bottles of Group II serum and Group III serum, labeled as below:

Serum II.		*Serum III.*	
Sodium citrate	1.5	Sodium citrate	1.5
Tricresol	0.25	Tricresol	0.25
Date		Date	

One bottle of each serum.

(2) Sterile sealed tubes of sodium citrate solution, with file mark for breaking point, labeled:
"Sodium citrate in 0.9 saline, quantity sufficient to citrate 600 c.c. of blood to 0.6; date.....," 48 tubes.

(3) Glass slides with II and III marked into the glass, in the upper left- and right-hand corner respectively, 12.

(4) Small tube containing small glass rods.

(5) Small bottle of alcohol for care of needles.

(6) Small bottle of ether for care of needles.

(7) Bottle of blood-counting fluid.

(8) Small metal tags (perforated) stamped to indicate the group of the patient:

Blood Group I	No. 10
Blood Group II	" 100
Blood Group III	" 20
Blood Group IV	" 100

(9) Small ball of twine for fastening tag to the individual grouped.

This box, well made and finished to carry the above supplies, was labeled: Laboratory Supplies, Transfusion, Medical Department, U. S. Army.

The Department of Laboratories should be induced to establish a laboratory supply and Wassermann service between the hospitals and the laboratory. Motor cycle side-cars or small automobiles serve this purpose admirably.

6. **Records.**—Definite records of transfusion work should be kept by transfusion workers in both the base and advanced areas. In the

latter, however, these notes must, of necessity, be brief because of the pressure of work, but they should be systematic and readily available. Transfusion workers must be required to send at stated intervals records of the work done to the Transfusion Committee itself where all data on that subject should be obtainable. The following is the type of record suggested for use in the transfusion work of the United States Army:

TRANSFUSION RECORD

Surname.....Christian name.....
Organization.....Rank.....Age.....
Register No.....
Transfusion done.....hours after injury.....
Hospital.....Date.....
Brief description of recipient's injuries and condition.....
.....
.....
.....
Clinical data.....
Laboratory data: Blood counts, etc.....
.....
Group of donor.....Group of recipient.....
Amount of blood given.....
Subsequent data and result.....
.....
.....
Wound healing.....
Date of discharge.....
.....
Transfusion worker.

7. The committee should establish and maintain at all times a liaison with the transfusion workers and should retain definite control of their activities. Such an arrangement requires of necessity that one member of the committee must be at all times in the field, in actual contact with the practical problems and difficulties. This plan gives an opportunity to place an estimate upon the quality of the men and to stimulate them to be systematic in the making of records and reports; moreover, it enables the committee itself to obtain continually first-hand information as to transfusion details.

8. In case the army is operating with other armies the committee should become familiar with the work in the transfusion field in the other armies, and should collect literature and information from all sources concerning transfusion activities.

9. **Conferences.**—These should be arranged at frequent intervals, which transfusion workers in the field may attend. At these times the daily problems of the work may be freely discussed.

10. Reports of the work done in the army should be made at regular intervals to the Department of Clinical Surgery and to the Department of Laboratories with constructive criticisms and suggestions.

III. DIAGNOSIS OF ACUTE ANEMIA FOLLOWING HEMORRHAGE AND INDICATIONS FOR TRANSFUSION

The differentiation of shock without hemorrhage from shock due to acute anemia from hemorrhage is difficult and sometimes impossible. Obvious extensive muscle injuries, some serious intra-abdominal lesions, and rapidly advancing acute infection, such as gas gangrene, may frequently be clearly recognized and the element of hemorrhage be eliminated. There are many cases, however, in which it is impossible to distinguish between shock without and shock with hemorrhage, for in many cases of pure shock the patient presents quite as blanched an appearance as a case suffering from hemorrhage, and the blood-pressure readings may be equally low in both conditions.

A history of extensive bleeding or obvious evidence of considerable hemorrhage or the presence of a large amount of intra-abdominal fluid within a few hours of injury and sometimes air-hunger are practically the only criteria for judgment. If in doubt, however, transfuse, as the additional 500 or 600 c.c. of blood usually introduced into the circulation is not sufficient to cause serious cardiac distress in cases of pure shock. In spite of all the experimental work done by investigators of the first rank there was little in the way of practical aid furnished to a surgeon in the front area to assist him in more accurately differentiating the shocked conditions with and without hemorrhage.

The symptoms of acute anemia following hemorrhage constitute the chief indications for transfusion. The immediate blood readings, made before the restoration of blood volume has been accomplished, may show little change in the hemoglobin or red cell count. Govaerts has laid down the principle that even a slight diminution of the red cell count, in the early hours after hemorrhage, is sufficient to determine whether or not the hemorrhage will be fatal.

He states that practically the hemorrhage is fatal when

Three hours after hemorrhage there are less than 4,500,000 red cells.

Eight hours after hemorrhage there are less than 4,000,000 red cells.

Twelve hours after hemorrhage there are less than 3,500,000 red cells.

In such cases transfusion of blood must be done if life is to be saved. Saline will be inefficient. Many surgeons have doubted the absolute practicability of this rule enunciated by Govaerts, but in general the principle is a safe working guide.

It is obvious that in a very active sector with mobility of the fighting line, it may be impossible to carry out the blood counting embodied in Govaerts' rule, but where a stable line exists such work is generally possible.

IV. SUBSTITUTES FOR BLOOD

With few exceptions advocates of the use of substitutes for blood agree that no substitute suggested is equal in its therapeutic value to blood itself. Rous and Wilson call attention to the fact that in anemia which follows serious hemorrhage the amount of hemoglobin in the body is usually double the quantity necessary to maintain life. They hold that it is not essential in the treatment of such an anemia to supply

blood-corpuscles themselves. Most of the experimental work done in the study of the immediate effects of hemorrhage in the animal organism leads to the conclusion that the chief thing from which the body is suffering is a diminution in blood bulk. The efforts that have been made, therefore, to provide these substitutes have been directed to the furnishing of fluid usually containing a colloidal preparation which will remain within the vessels over a considerable period of time. Rous and Wilson maintain that the viscosity of a blood substitute need not necessarily be the same as that of blood itself. Bayliss and also Hogan have gone so far as to claim that some of the colloidal preparations proposed are almost equal in efficiency to blood, and have not insisted upon a later transfusion, having the conviction that the colloidal substance itself will carry the patient through the critical period of post-hemorrhagic anemia. Nevertheless, it is the general belief that any substitute proposed must be considered as a purely temporary measure to tide over the case of serious hemorrhage until the time when blood can be made available to the patient. The three substitutes most generally used have been isotonic salt solution, solution of gelatin, and solution of gum acacia, while defibrinated blood, human serum, and horse-serum have also been considered.

1. **Defibrinated Blood.**—The use of this agent has practically been discarded. The preparation of it precludes any extensive use in front line surgery, and many observers have demonstrated that defibrinated blood is less efficient than whole blood in the conditions of anemia following hemorrhage. Moreover, Hedon's work seems to have proved that frequently defibrinated blood may be toxic to the recipient. We will, therefore, dismiss any further consideration of the use of this agent.

2. **Human Serum.**—For all practical purposes it is agreed that human serum would serve admirably to restore blood volume, provided it was a serum compatible with the patient's blood. It is obvious, however, that for the surgery of war it is about as difficult to obtain human serum as whole blood, and the latter is certainly more to be desired. We may therefore put aside the use of human serum as impracticable for war purposes.

3. **Horse-serum.**—This has been suggested as a possible fluid for restoration of blood bulk, but an amount sufficient to restore the volume would subject the patient to the risk of an anaphylactic reaction, which might prove serious and even fatal, and this objection alone suffices to dismiss horse-serum as a possible substitute.

4. **Isotonic Salt Solution.**—Saline was frequently employed in all of the Allied Armies. Its great advantages lie in the ease with which it may be prepared and the simplicity of its administration. The response of the patient to the intravenous introduction of saline solution is immediate. His general condition improves at once, with a rapid rise of blood-pressure, and this response is maintained, as a rule, for from one to five or six hours. De Page and Govaerts in 1917, however, placed themselves on record as to the inefficiency of saline given

intravenously where serious hemorrhage had occurred. David and Curtis and numerous investigators have demonstrated without question that a very rapid osmosis through the vessel wall occurs shortly after the introduction of the saline, this fluid finding its way into the fluid reserves of the body and the urine. This agent, therefore, should only be employed in those cases in which the blood bulk has been considerably diminished and where blood is not obtainable. It gives the surgeon a few hours in which he must make strenuous efforts to obtain blood for the patient.

5. **Gelatin Solution.**—Hogan in 1913 advocated the use of colloidal gelatin solution in shock, and included in his series several cases suffering from the shock of posthemorrhagic anemia. The preparation of gelatin as proposed by Hogan for intravenous administration is as follows: "Take 25 grams of the purest gelatin, it should be fresh and of high quality; 1.5 grams of sodium chlorid and 100 c.c. of distilled water are placed in a flask and boiled for fifteen minutes. The resulting solution is filtered through heavy paper in a hot funnel, and then autoclaved for an hour at 124° C. (255.2° F.). It is then chilled in an ice-box. The gelatin has the proper colloidal qualifications if under these circumstances it solidifies. In this form the gelatin is kept until needed. In order to prepare the transfusion mixture the flask of gelatin is warmed until it melts, when it is added to the 100 c.c. of 0.9 per cent. sodium chlorid, to which have been added 2 grams of sodium carbonate crystals all warmed to body temperature." Instructions must be carefully followed so that the heating of the gelatin is accomplished with a sufficient salt concentration, for otherwise decomposition of the gelatin will occur. Hogan reports good results in several cases of posthemorrhagic anemia, and is very enthusiastic about the efficacy of this agent. There was no general acceptance of Hogan's claims for gelatin in the medical services abroad, the objections which were raised being: first, the difficulties of procuring a pure product; second, the fact that the sterilization of the gelatin was difficult to accomplish; and, finally, the general objection to the introduction of a foreign colloidal substance into the circulation. Hogan apparently holds the conviction that the gelatin is as useful a therapeutic agent as the blood itself. This viewpoint is not considered sound by the vast majority of workers in the transfusion field.

6. **Gum Acacia.**—The chief exponents of the use of gum acacia are Bayliss, of the British Medical Service, and Cannon, of the American Medical Service. These two men carried on considerable experimental work in the use of this agent in shock. Their contention was that the main deficiency to be met in the organism was a restoration of blood volume, and their claims for gum acacia brought it prominently to the fore in the urgent front line surgery of both the British and American armies. A more or less permanent rise in blood-pressure is maintained with the use of a 7 per cent. gum arabic solution. The preparation of gum-salts solution is described by Bayliss:

"Commercial gum arabic is known to contain salts of calcium and

smaller amounts of potassium, magnesium, iron, and silicon. The commercial gum is treated with HCl and then alcohol is added, precipitating the gum with most of the inorganic elements. The solution should be filtered through flannel or chardin paper to eliminate pieces of wood. A 6 per cent. solution of the gum salts in water is then made by dissolving the precipitated gum in distilled water over a water-bath, giving a solution of similar viscosity to whole blood. To avoid hemolysis the gum solution should be dissolved in 0.9 per cent. sodium chlorid. The solution should be sterilized before using."

If the mucilage of acacia is utilized in preparing the gum solution, add 400 c.c. of H_2O to 150 c.c. of the mucilage; 4.5 grams of sodium chlorid is then added to the 500 c.c., giving a 0.9 per cent. solution in sodium chlorid. The amount usually given is 500 c.c.

Bayliss claims a distinct advantage over gelatin because of the difficulty of sterilization of the latter. Regardless of the extravagant claims made for gum acacia and the numerous enthusiastic users of it, and in spite of the fact that Cannon of the American Army advised its free employment, many disastrous results unquestionably followed its use. Under my own observation 4 patients who had received an intravenous injection of gum salts succumbed in from twenty minutes to half an hour following its injection, each of the 4 exhibiting symptoms strongly suggesting pulmonary embolism. Numerous other such disasters followed the use of gum solution in the hands of other army surgeons. Following this experience the gum solution was excluded from hospital units with which I was associated, and increasingly one found in the American Army fewer and fewer men who felt that the intravenous injection of gum salts was justifiable.

V. TECHNIC TO BE ADOPTED, INCLUDING THE NECESSARY APPARATUS

The method of transfusion for use in the field must be the simplest one which will give absolute satisfaction. The whole problem differs essentially from that in civil life. It is immediately apparent that many of the accepted methods of performing transfusion, which have given excellent results in prewar times, are not suitable in an active zone of an army. Although some workers, including Fullerton, Dreyer and Bazzett, as well as Hull, have attempted and successfully carried out an anastomosis by canula, direct methods had best be excluded as unsuitable for war service. Carrel's suture technic, or that with Crile's or Elsberg's cannula or Brewer's paraffined glass tubes, which are even now discarded in civil life, may be dismissed at once.

The large number of syringes necessary for Lindeman's method requires too much destructible material for war purposes, and, therefore, practically excludes it and Unger's method from consideration. Primrose and Ryerson's modifications of Lindeman's method where glass cannulæ are substituted for needles are also not applicable for war surgery. Bernheim's method is best excluded, this being the judgment of the originator of it himself. The Vincent technic, with the Kimpton-Brown paraffined tube, should also be dismissed, as the detail of paraffin

coating is bound to make the method somewhat cumbersome in forward areas. The exclusion of this latter technic was advised by Vincent personally. All of these technics named make it impossible to transport blood any distance, an essential feature being close proximity of donor and recipient. The method for war purposes, therefore, must take into consideration the possible needs of transportation of blood over a considerable distance. Further, many direct methods require the use of operating-room facilities, which are frequently overtaxed for operative work in a serious offensive.

The question of replacement of parts from the apparatus is also vital, as in times of great activity the problem of supplies becomes an all-important one. The apparatus determined upon, therefore, must be one which can have easily replaceable parts and these of the fewest possible number. The whole outfit must be compact to make it readily transportable, and should be capable of withstanding hard, continued usage. This narrows considerably the types of apparatus which might possibly be used. The methods to be considered, therefore, are:

A. Transfusion by the citrate method.

B. Robertson's preserved blood-cells.

A. The Transfusion of Blood by the Citrate Method.—In 1914 Weil, Hustin, and Agote began experimenting independently of each other, with the use of sodium citrate as an anticoagulant for blood transfusion. A little later Lewisohn advocated the use of the method, reporting a number of cases successfully transfused by its aid. He used a citration of 0.2, thereby keeping well below the limit of a toxic dose of 5 grams for an adult, as determined by Lespinard. Satterlee and Hooker in 1914 experimented with the use of citrate and hirudin. The latter substance has certain disadvantages over sodium citrate, one of them being its expense and the other the difficulty of obtaining it at the front.

Quoting the report upon transfusion for the United States Army: "The method by citrated blood has been adopted for general use because it is the most practical under war conditions. This method is the easiest to perform, requires less equipment, and has yielded good results. Any disadvantages it may have, such as the use of a chemical reagent, and a possible diminution in the coagulability of the recipient's blood, are virtually negligible."

In civil practice Lewisohn has been and still remains an ardent supporter of citrate transfusion. When it is realized that in the British, French, and American Armies the method ultimately adopted was some form of citrate transfusion, it is evident that this means of blood transfer appealed to all as the simplest and most practical for war purposes.

Four methods by citrated blood having proved their usefulness in active areas have been chosen for consideration, namely:

(*a*) The U. S. A. apparatus.

(*b*) Robertson's apparatus.

(*c*) Jeanbrau's tube.

(*d*) Lewisohn's technic.

(*a*) **The U. S. A. Apparatus.**—The apparatus originally planned for the American Army was later modified, as certain defects were discovered. The revised apparatus is the one here described.

The essentials necessary for the carrying out of this method are an ordinary bottle with fairly wide mouth and of 1 liter capacity, a perforated rubber stopper, glass and rubber tubing of proper caliber, a transfusion cannula, a rubber suction and compression bulb, and a series of transfusion needles. These are made of steel. The total length of each needle is 4 cm.; the length of the shaft is 2.5 cm., the length of the point is 4 mm., the length of the base 1.5 cm. with a flat portion on two opposing sides. The size of the needles and number required are: 25/10 mm., 2; 20/10 mm., 2; 16/10 mm., 2; 13/10 mm., 2. They must be sharp and the operator must attend to this detail himself.

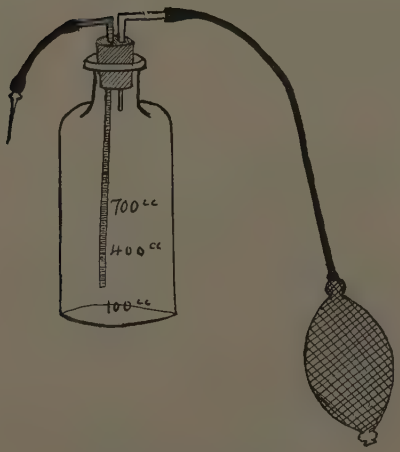

FIG. 90.—WITHDRAWAL SYSTEM U. S. A. APPARATUS.

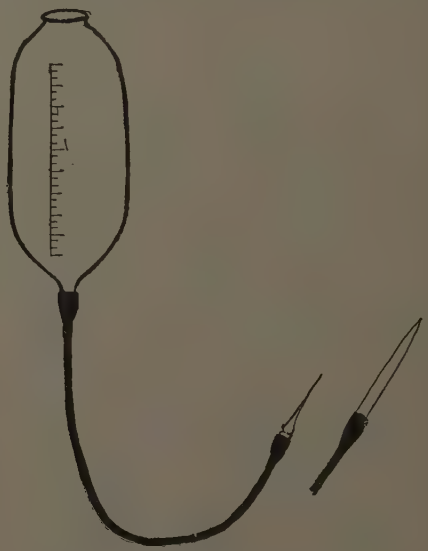

FIG. 91.—METHOD OF INTRODUCTION U. S. A. APPARATUS.

The bottle has three marks—at 100, 400, and 700 c.c. The apparatus is sterilized either in an autoclave or by boiling, and is then assembled as shown in the diagram. The glass tube containing the sodium citrate solution provided by the department of laboratories is broken off at the file mark, and the open mouth having been flamed, the solution is poured into the bottle. The citration provided is 0.6 per cent. for 600 c.c. of blood; 100 c.c. of saline is then added. This solution must be rinsed about in the bottle, which coats it with this diluted citrate solution. The rubber tube leading to the withdrawal needle should be short, the glass tube to which it is attached should be of good-sized caliber, and the end of the glass tube within the bottle should extend to within a short distance of the bottom of the container. The largest sized needle that can be managed should be made use of, as this increases the rate of flow of the blood and diminishes the liability to clotting.

Before attempting to withdraw any blood the bulb placed to exert compression should force the diluted citrate out into the collecting system and through the needle.

A tourniquet is placed about the arm, endeavoring to produce the largest degree of venous pressure. A blood-pressure cuff may be utilized, using a pressure of about 80 mm. of Hg. Strict asepsis must be maintained. The blood is withdrawn by the entry of the needle into some accessible, good-sized, superficial vein, and immediately suction with the bulb should be begun. (*Note:* In the original U. S. A. apparatus suction was accomplished by means of a glass cotton-plugged mouthpiece, but this was later discarded for the suction bulb, as a safer, easier method.) As the blood enters the bottle gentle agitation of the container brings about an intimate admixture between blood and citrate, and a clot will not form. The blood, so citrated, may be kept for upward of twenty-four hours, and will readily stand transportation. In the June, 1918, offensive for a limited period a courier service with citrated blood from a hospital further back was established, to one of the more forward units, and citrated blood was kept in the operating room, where it was immediately available to the shocked man needing it.

The rule in the U. S. Army limited the amount to be taken from any one donor to 600 c.c. The reasons for this decision were that this amount usually sufficed to tide over the man suffering from hemorrhage and a larger amount removed may cause considerable distress to the donor. If more blood is required, an additional donor is used. In no event is the same donor to be used twice in the same week.

At first an attempt was made to introduce the citrated blood by means of a siphon principle plus compression, but later it was found simpler and more efficient to introduce the blood as one would saline, using either a glass funnel or a saline infusion container, filtering the blood through gauze, if any question of minute clotting was present, but there should be no clot if the technic has been correct. Where the veins of the recipient are considerably collapsed, the canula is used rather than the needle. The apparatus must be carefully cleaned with cold water immediately after using it. The needles require special attention.

In the hands of the American surgeons the method outlined above proved its usefulness in the active zone, and with the modifications mentioned it was a very satisfactory method.

(*b*) **Robertson's Apparatus for Citrated Blood Transfusion.**—Briefly, Robertson's apparatus for citrated transfusion makes use of the same receptacle for the bleeding and the transfusion. The special points upon which he lays stress are a short bottle with a large opening of 900 to 1000 c.c. capacity—the shorter the bottle, the shorter the introductory tube. Three marks are placed upon the bottle at the level of 660, 760, and 860 c.c., corresponding respectively to 500, 600 and 700 c.c. of blood. A solution of 160 c.c. of 3.8 per cent. of iso-citrate of sodium is poured into a bottle, having been made with recently distilled water and filtered. This is covered with a cotton stopper and gauze,

and sterilized one-half hour in an autoclave at 105° C. A half-dozen of such bottles may be prepared at one time.

The needle for the withdrawing of the blood and its care will be completely described under the method of Preserved Red Blood-cells, outlined by Robertson, and the manner of bleeding is identical with that described under that method. The needle employed for the drawing of blood is likewise of the same type as that advised for the Preserved Red Cells Transfusion. He particularly advises a large glass inlet tube of a caliber of 6 mm. internal diameter, which is so placed as to reach the bottom of the bottle below the level of the citrate solution. The transfusing part of the apparatus, the long glass tube in the bottle, descends nearly to the very lowest level of the container. He also pumps citrate solution out through the glass tube and withdrawing needle before attempting to withdraw the blood. For a tourniquet he sometimes uses a blood-pressure cuff with a pressure of 50 to 60 mm. of

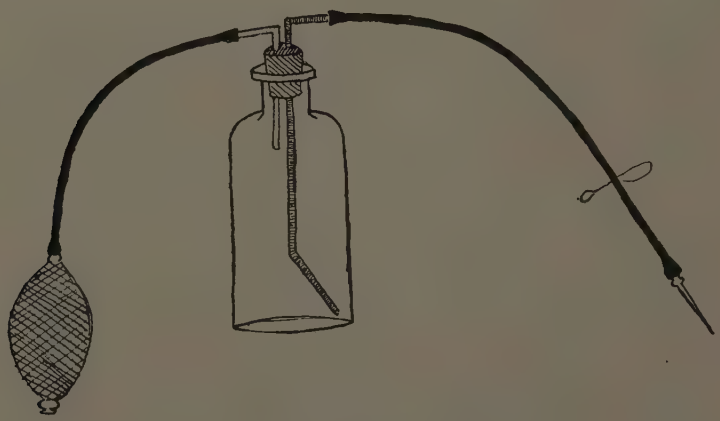

FIG. 92.—ROBERTSON'S APPARATUS.

mercury. After injection of novocain, a small nick is made in the skin by the point of a knife, and with a light aspiration in the bottle the needle is introduced a short distance beneath the skin entering the vein. If the donor's veins are too small for the needle, a cannula is resorted to. At the termination of the transfusion he always closes the clamp on the rubber tube close to the transfusion needle to prevent air bubbles entering the vein. With this method it is difficult to remove more than 700 or 800 c.c. of blood, but it is seldom necessary to take even this amount for transfusion purposes. With the latter amount the mixture furnishes a citration of 0.6 per cent. The method can be done by a single individual, and is simple and rapidly executed.

(*c*) **Jeanbrau's Method.**—In May, 1917 Jeanbrau first made use of a modified Kimpton-Brown tube, enlarging its capacity to 500 c.c. He omitted the use of paraffin and, encouraged by Hedon, began the employment of sodium citrate solution within the tube itself, where direct admixture with the blood was accomplished. Other points in the

technic followed fairly closely those developed and extensively used by Vincent.

The tube is sterilized in the autoclave or by boiling. Sterilized sodium citrate solution sufficient to approximate a citration of 0.4 per cent. for 500 c.c. of blood is introduced into the tube, and is agitated in such a manner as to bring it in contact with every part of the inner surface of the ampule. The tube is marked to indicate the amount of citrate present and also the withdrawal of either 250 or 500 c.c. Before aspiration of the blood a slight amount of citrate is permitted to escape, a precautionary measure practised to prevent coagulation of blood in the tip. The veins are exposed under local anesthesia, the withdrawal being from the distal end, the transfusion into the proximal end, ligatures having been placed in each instance upon the other part of the vein. An assistant is required to manage the bulb, suction being used in withdrawal and compression in the administration of the blood. Gentle agitation of the ampule during aspiration brings about a satis-

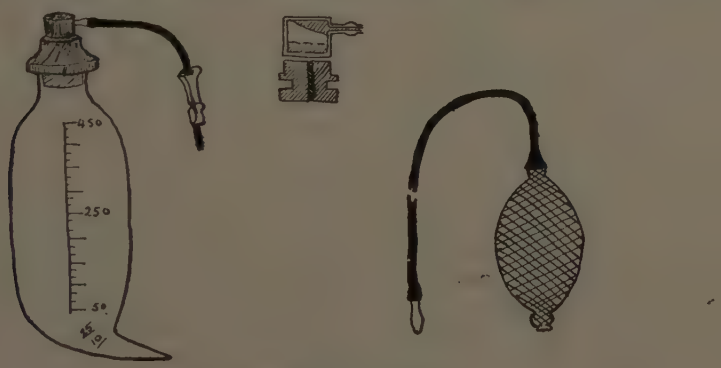

Fig. 93.—Jeanbrau's Apparatus.

factory mixture of blood and citrate. As the withdrawal is finished, a small amount of blood is allowed to escape from the tip, where citration has not been possible.

As compression is exerted, the rubber stopper in the top of the container must be firmly held in place to avoid its expulsion. The operation requires about twenty minutes.

The disadvantage of the method lies in the necessity for cutting down upon the vein, so that the donor's vein may not be made use of again for an additional transfusion. Further, as no use is made of a needling technic, surgeons rather than medical men are necessary for the operation.

In the hands of Jeanbrau the method yielded excellent results, and many other French surgeons were enthusiastic in favor of this technic.

(*d*) **Lewisohn's Method.**—This method is the simplest of all, and for that reason has much to commend it. He simply bleeds through a large needle into a glass container with citrate solution sufficient to citrate the blood to 0.2 per cent. Agitation of the vessel during aspira-

tion gives an efficient citration. The citrated blood is then introduced as one would introduce saline solution, using any container available, and a needle or cannula for the introduction into the recipient's veins. Obviously, the main criticism is the low degree of citration used by Lewisohn. The U. S. A. Committee and Robertson agree that citration should be carried to 0.5 or 0.6 per cent.

In the British Army many workers made use of Lewisohn's principle in transfusion, and they have attained with it all that more complicated methods have yielded.

B. **The Transfusion of Blood with Preserved Red Blood-cells (Robertson).**—The author of this ingenious and very useful method was led to its use because of the difficulty of procuring a sufficient quantity of whole blood for transfusion purposes at any given time in an advanced hospital. The method, therefore, allows the collection of red blood-cells preserved in a dextrose-sodium citrated solution which may be kept for from three to four weeks at a time without material change of the red cells, which may be collected during quiet periods and held in readiness for the day of greatest need. The experimental basis of the method was furnished by the work of Rous and Turner, carried on in the early years of the war. These investigators found the blood-cells could be preserved for a considerable period in a solution of dextrose and citrate of soda.

For the complete description of the method reference should be made to Robertson's original contribution. Certain important details should, however, be properly considered here. The isotonic solutions of sodium citrate and of dextrose are prepared with distilled water and are sterilized separately. The iso-dextrose may be made in considerable quantity (sufficient for six transfusions), must be filtered, and should be sterilized if it is not to be used shortly. The temperature in the autoclave must not be in excess of 105° F., at which temperature decomposition of the dextrose occurs. The iso-citrate is similarly prepared, and is sterilized in bottles similar to those which are to be used in the actual transfusion.

The withdrawal apparatus is practically the same as that pictured in Fig. 92. The container for the dextrose solution is utilized as the transfusion bottle, and marks are made upon the container indicating the levels for the isotonic solutions and the amount of blood to be aspirated (500 c.c.). Robertson lays much stress upon the importance of the needle in the operation. Its caliber should be large (1.5 mm.) and its length 3.5 cm. and an olive-shaped base is desirable. It should be sharpened before each operation, and its after-care is vital to the success of the bleeding.

The rubber tube connecting with the withdrawal needle should be short and flexible. The glass tube should have a diameter within of 6 mm. and should reach well beneath the level of the iso-dextrose-citrate fluid. Elbow veins are usually employed; the usual precautions as to asepsis are taken and local anesthesia is used. The withdrawal system is filled with the dextrose-citrate solution. The vein is entered, and

aspiration is accomplished by means of the bulb, which has now been reversed. The needle must be held stationary and the patient's arm should not be moved. No special effort should be made to mix the blood with the solution during the withdrawal, but later a slight agitation of the bottle is desirable. The fluid is set aside, upon ice, with a cotton stopper in the bottle.

The blood is obtained quickly and easily. As Robertson states, "one of the greatest objections to the method is the fact that the blood is not able to be immediately utilized." It requires four or five days before the cells may be used in a transfusion. If the surgeon desires the cells more quickly the amount withdrawn should be 300 c.c. in place of 500 c.c. The supernatant liquid has a definite opalescence due to the suspended red cells. One should suspect hemolysis if this fluid has a persistent rosy hue. Four weeks seems the limit in which the cells may be safely used. The suspended cells are obtained by siphonage. The equivalent of the original blood volume removed is obtained by adding saline or normal serum to the suspended cell fluid. The liquid is mixed by gentle manipulation of the container and then filtered through gauze to remove any minute clots. The bottle and its contents are then warmed by being placed in a hot water-bath the temperature of which is 106° F., and during the administration of the blood-cells the bottle is continued in this bath.

The transfusion is accomplished by compression with a rubber bulb, the stopper in the bottle being held in place by adhesive strips. The needle used is of definitely smaller caliber than the one used for aspiration. Robertson points out the distinct advantage of the needle over a cannula (which may be needed with very collapsed veins), as the former permits a slower rate of entry of the suspended cells.

Transfusion with preserved blood produces the same effects as that produced by transfusion of whole blood; there are the same marked improvements in the patient's color, the pulse becomes full and strong, and blood-pressure rises 20 to 40 mm. In the days that succeed the transfusion this improvement remains or is still more marked.

This method, proposed and carried out by Robertson with such excellent results in his work with the British Army, has much to commend it. It has a certain definite field in the surgery of war, one of its main advantages being that blood may be obtained some distance to the rear of an active zone, where donors are more readily available, and brought forward to the hospital, where it may be stored for the day of necessity. Upon the other hand, however, it obviously entails too much in the way of detail to be the one method for an army in the field to adopt. There are many points of rather fine technic, which, in the hands of a thoroughly trained laboratory man, are easily performed, but which the average army surgeon would not follow through successfully. We conclude, therefore, that the method in trained hands might properly be used at evacuation hospitals or C. C. S., and would undoubtedly save many lives, but as a routine measure with the present technic suggested it can never be adopted.

Robertson's Preserved Blood-cell Technic is suitable for evacuation hospital purposes, where, in the hands of experienced laboratory workers, it will give excellent results. The niceties of detail required preclude its general adoption for an army in the field.

VI. SELECTION OF DONORS AND SUPPLY OF DONORS

I was the chairman of a committee appointed to draw up the transfusion report for the United States Army in France. The tersest possible language was aimed at in this pamphlet clearly to outline the donor problem and the interrelation of blood groups; and these subjects will therefore be quoted verbatim. A few additional data have, however, been added to emphasize special points:

"Our knowledge of the four blood groups has proved to have a very practical value in blood transfusion. Hemolysis does not take place between individuals belonging to the same blood group, and practically never takes place between certain definite combinations of different groups. Having determined the blood group, it is possible to select a donor whose blood is compatible, as regards hemolysis, with the blood of the recipient."

A. **Blood Groups.**—"Every individual may be classified in one of four groups, according to the agglutinative reaction of his serum and corpuscles with the sera and corpuscles of individuals of the three other groups. Hemolysis never occurs when agglutination is absent; hence the agglutinative reaction determines the possibility of hemolysis.

"The classification of these groups described by Moss is as follows:

"Group 1. Serum agglutinates no corpuscles. Corpuscles agglutinated by sera of Groups II, III, and IV.

"Group II. Serum agglutinates corpuscles of Groups I and III. Corpuscles agglutinated by sera of Groups III and IV.

"Group III. Serum agglutinates corpuscles of Groups I and II. Corpuscles agglutinated by sera of Groups II and IV.

"Groups IV. Serum agglutinates corpuscles of Groups I, II, and III. Corpuscles are not agglutinated by any serum."

The approximate percentages in round numbers are:

Group I, 5 per cent.; Group II, 40 per cent.; Group III, 10 per cent.; Group IV, 45 per cent.

(The actual percentages are: I, 3.8 per cent.; II, 42 per cent.; III, 8.9 per cent.; IV, 46 per cent.)

It will be noted that this classification of Moss' is the reverse of Landsteiner's classification, which antedated Moss' a short time; on this account Hooker, Coca, and others have advised the use of the Landsteiner classification rather than that of Moss. Considering the fact that Moss' work was entirely independent of Landsteiner, even though the former has a few months' priority, and considering also that in most American hospitals where transfusion has been seriously attempted the Moss classification has been followed, I believe that in America we should follow Moss' nomenclature.

The following table shows the relation of the four blood groups with respect to agglutination:

	I	II	III	IV
I	0	+	+	+
II	0	0	+	+
III	0	+	0	+
IV	0	0	0	0

+ = agglutination; 0 — no agglutination.

B. **Method of Determining Blood Groups.**—In order to determine the group of an individual it is sufficient to test his corpuscles against sera of Groups II and III. This is readily accomplished by a macroscopic test described by Vincent, which, in addition to the two known sera, requires only a glass slide, a needle, and two small glass rods. This test of Vincent's has simplified the whole subject of practical blood grouping, and has also contributed much to make transfusion safe in an active war zone. Citrated sera for this test were furnished by the Division of Laboratories.

The preparation of the serum is accomplished by collecting 20 c.c. of blood from individuals known to belong to Groups II and III. When the blood has completely coagulated, the serum is drawn off into separate sterile containers, and sodium citrate sufficient to produce 1.5 per cent. citration and tricresol to 0.25 per cent. are added. As Vincent describes, the citration is done to prevent coagulation of the tested blood when mixed with the serum. The addition of the preservative keeps the serum sterile, although Vincent has seen serum a year old and contaminated apparently as active as fresh serum.

"The test is performed as follows: Place a drop of Group II serum on the left half of a glass slide (slide need not be sterile, but should be clean and dry) and a drop of Group III serum on the right half of the slide. Puncture the ear or finger of the individual to be tested, and transfer in turn to each of the sera about $\frac{1}{3}$ drop of blood, on the end of the glass rod, mixing the blood intimately with the serum. In making the test care should be taken to transfer the blood before coagulation has commenced, and also to avoid mixing the two sera. A separate glass rod should be used for each transfer. Agitation of the slide accelerates the appearance of an agglutination.

"The red cells make a uniform suspension in the citrated serum. If there is no agglutination and the test is negative, this suspension persists. If the test is positive and agglutination takes place, it usually appears in less than a minute in the form of masses of agglutinated cells, easily discernible to the naked eye. In the rare instances in which the reaction is questionable the donor should not be used."

Rarely there is a tendency to rouleaux formation which may be confusing. Rouleaux formation appears more slowly than agglutination, and, contrary to agglutination, is dissipated if the rouleaux are broken up by stirring the serum."

Other methods of grouping than Vincent's have been described, such as that by Roger Lee and the one by Brehm, but none of them are

as simple or as rapid, or are any more accurate. The person doing the grouping should always observe the precaution to discard doubtful reactions, for there is much individual variation in the agglutinative reaction of members of the same blood group. In spite of statements

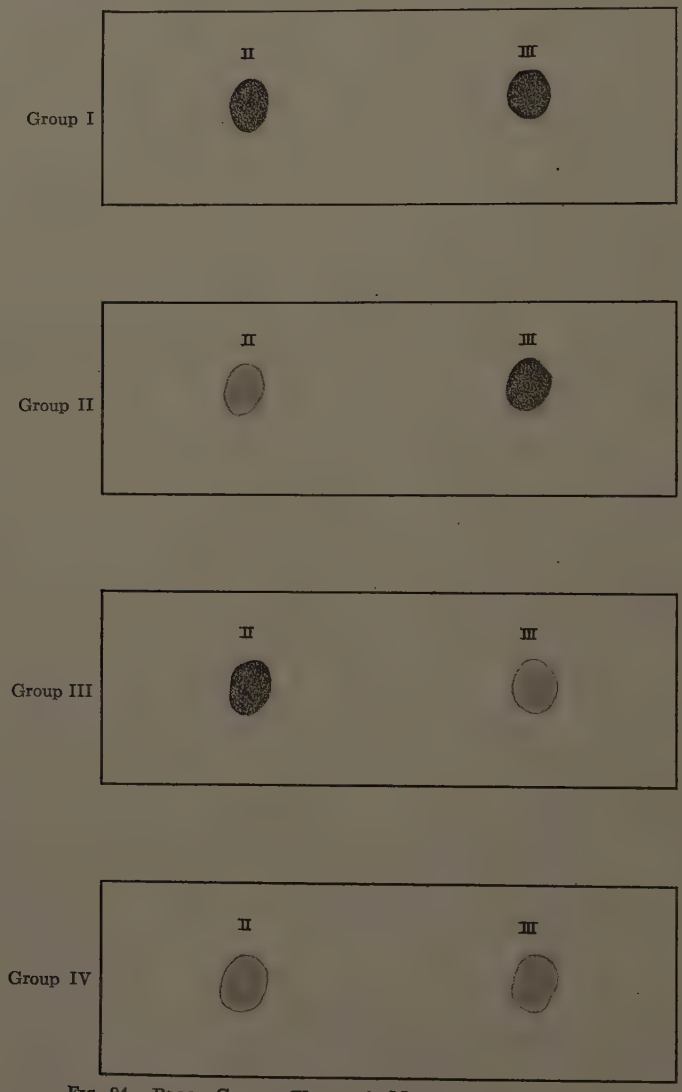

FIG. 94.—BLOOD GROUPS (VINCENT'S MACROSCOPIC AGGLUTINATION TEST).

by McClure to the contrary, no difficulties will be encountered if only clean-cut group reactions are made use of.

It is also vitally important that the Group II and Group III sera used should be those showing strong agglutinative reactions.

Abelmann uses what he calls the biologic test, which consists of

injecting about 40 c.c. of a donor's blood, to which sodium citrate and saline have been added, and observing the effect upon the recipient. If the precautions mentioned above have been followed in the group test by Vincent, it is thoroughly satisfactory, and the biologic test need not be used.

C. **Selection of a Suitable Group to Use as Donor.**—"Except in cases where the risk of delay is greater than the risk of hemolysis, the compatibility of the blood of donor and recipient should be determined before doing blood transfusion. Where possible, the donor should be selected from the same group as the one to which the recipient belongs. This is usually easy when the patient is a member of Group II or Group IV (common groups), but may be difficult when the patient is a member of Group I or Group III. For these latter groups a Group IV donor is much more readily available. Where a donor of the same group is not available, Group IV donors may be used for any of the four groups. Group IV corpuscles are not agglutinated by any serum, and the agglutinative reaction of Group IV serum upon the corpuscles of any of the three other groups is unimportant, because the serum is promptly diluted by the serum of the recipient. Hence, members of Group IV are termed "universal donors." The serum of Group I does not agglutinate the corpuscles of any group, therefore members of Group I may be transfused from any of the four groups. Hence, members of Group I may be termed "universal recipients."

"The above may be expressed in tabular form as follows:

"*If recipient is Group I*, donor may be selected from Groups I, II, III, or IV.

"*If recipient is Group II*, donor may be selected from Groups II or IV.

"*If recipient is Group III*, donor may be selected from Groups III or IV.

"*If recipient is Group IV*, donor should be also Group IV."

D. **Other Requisites in a Donor.**—(1) In general, convalescent patients constitute the class from which to select donors, and those slightly gassed or with minor surgical injuries are usually available. A careful selection should be made from among this group. As a rule, in the forward areas personnel is not available for donor purposes; further back, where work is less active, they may perfectly well be used.

(2) One must select a non-febrile patient in good physical condition.

(3) Every means at hand must be used to exclude as donors men affected with communicable diseases, especially syphilis.

(4) No reward is to be offered a donor, and the donor's consent must be obtained without urging or compulsion.

In both the British and French Armies some type of recompense was given the donor, an additional leave being the usual reward. The American committee preferred to place the whole matter upon a line of duty status with the privilege of volunteering optional, and the fine spirit displayed justified the judgment of the committee.

E. **List of Available Donors in the Operating Room.**—It is essential to have a list of donors, with their grouping, posted in the opera-

ting room. When necessity arises a donor is thus immediately obtainable. To avoid a possibility of error this list should provide every possible means for properly identifying the donor. In order to assure absolute identification small perforated metal tags are provided, marked to indicate the group to which the man belongs. This tag must be attached to the man by the individual making the test at the time the grouping is determined.

The operating room list should show the following data:

List of Available Donors.

No.	Name.	Age.	Ward.	Bed.	Group.
1.	John Smith	22	6	29	IV
2.	Frank Jones	24	3	24	IV
7.	Edward Wilson	20	2	21	II
8.	William Hennessy	22	4	23	III

VII. BLOOD REACTIONS OF THE RECIPIENT FOLLOWING CITRATED TRANSFUSION

The laboratory researches of Giraud give a very accurate idea of the changes which take place in blood which has been citrated. Giraud enumerates these as follows:

1. In citrated blood a stabilization of calcium is brought about rendering it inactive. Such a blood is not affected by contact with a foreign material.

2. The coefficient of viscosity in blood which has been citrated is constant.

3. Citrated blood has a slightly lower cryoscopic point than normal blood.

4. Hemolysis does not occur in citration over 3 per cent.

5. Citration of a blood does not interfere with the change from hemoglobin into oxyhemoglobin, and thus does not interfere with the hemostatic power of blood.

6. In blood which has been citrated for a few hours slight cell distortion is found. "If citrated blood showing slight cell distortion has glucose serum (5.4 per cent.) of Rous added to it, the cells regain their form. The proportions are blood, 2 parts; citrate (3.8 per cent.), 3 parts; glucose serum, 5 parts."

7. Toxicity of citrate. As demonstrated by Sabbatinni, this is due to the deposit of calcium in the tissues, especially in the nerve centers. It has been shown that 10 grams of citrate will inactivate all the calcium of the circulating blood of the human organism. A citration of 4 per cent. Giraud considers perfectly safe.

The cause of the reaction following transfusion, as pointed out by Drinker, may be due to a gross incompatibility with definite hemolysis or to other factors. These causes may be summarized as follows:

(*a*) Incompatible bloods with definite hemolysis.

(*b*) Certain changes which the platelets may undergo in connection with coagulation.

(*c*) The action of the sodium citrate upon the red cells.

Ashby, in an inquiry into the good results following citrate trans-

fusion, found that it was possible to determine that transfused corpuscles remained alive for thirty days or more in the recipient's blood. This differentiation of the corpuscles was accomplished by using the principle of agglutinative reaction. He therefore concluded that the beneficial effects of the transfusion were due not only to increase in blood bulk and the stimulation of the hemopoietic function, but also by actually increasing the number of cells themselves for a considerable period.

McClure has maintained that improper matching of the blood is apt to occur resulting in unfavorable symptoms from hemolysis. When the precaution is observed of having a strongly reacting Group II and III serum, and discarding all questionable reactions, few instances are on record of definite hemolysis. Under our own observation abroad no serious hemolytic symptoms were encountered, as testing was very carefully done along the lines indicated. He reports one death in 150 cases from hemolysis following improper grouping of the patients. McClure also calls attention to the difficulty of grouping patients after repeated transfusions, although he has never observed a change in a group following several transfusions.

Melaney, Stearns, Fortuine, and Ferry report 63.6 per cent. of posttransfusion reactions in 280 transfusions. They found that a recipient in good general health usually gave a more definite reaction than one in poor health. They further concluded that the occurrence of a reaction was in no way determined by the type of transfusion performed, the particular group to which the recipient belonged, or the blood relationship of donor and recipient. Where amounts of blood less than 200 c.c. are introduced the reaction was less likely than where larger amounts were employed. They found, further, the more times a patient was transfused, the more likely he was to show reaction. They also report some cases with a considerable leukocytosis following transfusion, which they attribute to either an intravascular hemolysis or the formation of certain toxic products in the blood.

Sydenstricker encountered 17 per cent. of reactions where previously compatible bloods had been proved. He considers that any single symptom or combination of symptoms occurring within three hours of the transfusion should be considered a reaction. It is well, therefore, for the transfusion operator to bear in mind the symptoms of hemolysis which, if progressive and ominous, would indicate an immediate cessation of the transfusion. Sometimes within a half-hour or even an hour after the transfusion mild symptoms may be noted which may probably be ascribed to certain degrees of hemolysis. These are a slight headache, malaise, urticaria, a rise in temperature (many considering a rise of over 1 degree indicative of a distinct reaction), chilly sensation, and even a definite rigor, and complaint of pain and compression about the chest with dyspnea, dilation of the pupils, increase of perspiration, increase of pulse-rate. There may also be a hemoglobinuria, and in serious cases the patient may pass into an acute anaphylactic shock, from which he may not recover.

In spite of all this evidence which we have quoted of the frequency of hemolysis, with the emphasis laid upon the serious symptoms which may be encountered, the practical experience abroad taught that with the safeguards mentioned in connection with the grouping and the instruction in transfusion in force, as outlined in the paragraph upon organization, no untoward results followed, making the objections to the use of a citration method practically negligible.

VIII. RESULTS

Depage and Govaerts in 1917 reported 14 cases transfused up to that time, 8 having been evacuated in good condition. Of the 6 fatal cases, 1 died of hemolysis with marked hemoglobinuria, no grouping having been done; 2 of the others died of gas bacillus infection, while in 2 other cases an insufficient amount of blood was given. Hallopeau, Delivet, and Gelas reported in the same year 12 cases, with a recovery rate of 58 per cent.

In 1918 the importance of blood grouping and its ease of accomplishment was brought home to the Allied Armies, and a better choice of cases was being made than in the earlier years. Unfortunately, no complete data are available giving the statistics for the American Army. Transfusion was, however, very frequently employed, and many a man, suffering seriously from the effects of hemorrhage, was saved by its use. I take the liberty of quoting from a report by Lieutenant A. M. Hansen sent to me in June, 1918, following a service with transfusion at Juilly, where in the early days of June enormous numbers of seriously wounded men were received from the Second American Division: "Slight as my experience has been with this method of blood transfusion (U. S. A. apparatus with canulæ, using Carrel container to administer the blood), I know that at this hospital we have saved lives by its use which would otherwise have been lost, and its simplicity recommends itself to a service in war time—for no one who has conscientiously tried can say 'it can't be done.' "

As definite reports are made in the literature, the exact figures for the transfusion results will be evident. No one, however, who has passed through the experience of surgery in the front area and has seen transfusion prove itself a life-saving measure over and over again could have any doubt of its efficacy. There is one point which should always be borne in mind where statistics are quoted in connection with war surgery, namely, that the surgeon is playing for lives and not figures, his object being to give every man a genuine chance for life. With such a working ideal statistics are misleading, and it may be that the surgeon with the poorest statistical record may have been the one to have saved the greatest number of lives.

In connection with transfusion work the lessons learned in the war zone which may be applied to civil practice are important ones. It has stimulated the civilian surgeon to even more prompt decision and quicker action than the prewar times knew of. It has shown that the man and not the method is the important factor in success. It has

taught us in civil life to study more carefully the red cell counts and hemoglobin after hemorrhage, and to appreciate that a small drop in either may indicate a serious hemorrhage, and that a small amount of blood (500 c.c.) is usually sufficient to save the life of the patient. It has emphasized again and again the safety of transfusion where grouping has been carefully done. The demonstration by Robertson, that preserved red blood-cells are as useful as whole blood for the case of severe hemorrhage, has opened up a wide field for study and investigation in civil practice, with the possibility of important applications. Above all, to every civilian surgeon transfusion in war has brought home the great necessity for the collection of accurate data on all its phases, that the more intricate reactions associated with its use may be clearly understood and appreciated.

IX. CONCLUSIONS

Every medical department of every army should make provision for transfusion in their plans for active medical service. This effort should be carefully organized and controlled to attain its maximum efficiency.

No blood substitute has yet been found really to take the place of blood after serious hemorrhage, and gum acacia is an unsafe agent.

The citrate method is the one of choice for front-line work and should be adopted for the entire medical service.

Robertson's preserved blood-cells is an efficient means of counteracting the effects of hemorrhage, but its use must be limited to trained laboratory workers.

Convalescent patients or the slightly wounded or gassed constitute the class from which to choose donors.

Vincent's macroscopic test is the simplest and best method to determine the blood groups.

Blood reactions are never alarming if grouping is properly done, and if donors showing doubtful reactions are discarded.

No real light has yet been thrown upon the differentiation, from a diagnostic viewpoint, between shock with and without hemorrhage, and further experimental work is needful to clarify this subject.

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CHAPTER XIV

THE BACTERIOLOGY OF WAR WOUNDS

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The salient feature of war wounds, or battle casualties, as they are sometimes called, is the great amount of subcutaneous destruction of tissues caused by the passage of the projectile. The external appearances of the wounds of entrance or exit afford no indication as to the amount of internal harm done. The waves of centrifugal force set in action by the passage of the projectile not only cause an unusual amount of devitalization of the neighboring tissues but also scatter widely minute particles of clothing, hair, soil, spicules of bone, and, most important of all, bacteria. Sections of tissue taken from the track of a projectile show such particles and bacteria scattered throughout the tissues to a depth of 1, 2, or more cm. With the focus of infection in such devitalized tissue already at hand, it is readily apparent how important the operation of débridement and excision of such tissue becomes. The soil of the terrain over which the troops are fighting is, for the most part, highly fertilized, and contains large numbers of bacteria, particularly the anaërobic bacilli. The clothing and skin necessarily become contaminated with this soil, and it is for this reason that the projectile in its passage carries with it the means of infection.

Wounds received in civil life, on the other hand, are only in a small percentage of cases of the penetrating or perforating variety. Hence, it is rare that conditions are such as to allow the development of anaërobic bacilli, which we find to be the case in nearly all war wounds left untreated or improperly treated. Furthermore, we do not find the same degree of devitalization of tissues caused by waves of centrifugal force, such as is seen in wounds caused by projectiles.

So far as the bacterial flora of wounds in civil life is concerned, it is quite possible that most of the bacteria found in war wounds may have been present in wounds of civil life, but it has not been the practice of bacteriologists to distinguish more than a few common varieties. This is practically true where we have had to deal with wounds received in the streets and fields where the bacterial flora might approximate that found in the fields of warfare.

WAR WOUNDS

In this study we will first consider the relations which should exist between the surgical services and the wound bacteriologist. *Never*

in the history of surgery have the surgeon and the bacteriologist been brought into such intimate daily contact. The surgeon wishes to know not only the character of the infection, but the possibility and the time for performing a primary, delayed primary, or a secondary closure. It has been demonstrated beyond a doubt that the surgeon who closes a wound, *apart from primary closures*, without all the available bacteriologic data at hand, may assume an unjustifiable responsibility. On the other hand, when the surgeon neglects to close a wound, which from the smears and cultures might be done, he may deprive the patient of an opportunity for a quick recovery, and add a great expense to the government in the care and treatment of the patient. In addition to which it must be remembered that the functional result of a wound healing by first intention after a primary or delayed primary closure is at almost all times better than that following secondary closure, or healing by granulation.

Before taking up the discussion as to the procedures which are most applicable to the bacteriologic study of war wounds, it may be inquired what are the most important periods of a wound when cultures and smears should be taken. Should the culture be taken from the wound on entrance, before operation, during operation, after operation, or at the first subsequent dressing? Here, as in many other questions of routine, it depends upon how much time the bacteriologist has at his disposal. If he has not too much to do, he may take cultures and smears at all of these times, and thereby get a very accurate impression of the bacterial condition of the wound. It has been laid down as a maxim by many of the French observers that it is impossible to find bacteria microscopically in a bleeding wound less than six to eight hours old. Up to that time the wound is practically sterile, the few bacteria taken in by the projectile not having had time to proliferate. Cultures taken during this interval may also prove to be sterile.

Cultures taken from a series of wounds before, during, and after operation are of great comparative interest, but not necessarily of corresponding value. In many cases during operation direct cultures from the tissues and exudates, as well as projectiles, including stones, fragments of bone, and pieces of clothing, may be taken, all of which should be cultured in suitable media. Sections of devitalized muscle or other tissue removed during operation should also be cultured and carefully examined. What, then, is the best time, from the point of view of the surgeon, for taking cultures and smears, and why?

It is very obvious that the bacterial flora of a wound before and even during an operation will be entirely different from that found later, owing to the very nature of the operation. The modern operation of débridement and excision presupposes the removal of a comparatively wide margin of healthy tissue containing all the devitalized and infected tissues, extreme care being used to prevent the contamination of the walls and margins of the cavity thus produced. In this mass of tissue thus removed it is assumed that all of the infecting organisms are included. Assuming that the operation has been thoroughly carried

out, it has been demonstrated in a large number of cases that the bacteria have been entirely removed, or so few left behind that they have been prevented by the body tissues and fluids from proliferating. The determining of the original bacterial flora in such a case is of much greater interest to the bacteriologist than it is to the surgeon, for the latter may take it for granted that he no longer has the original flora to deal with. Should a culture be taken, then, at the completion of the operation, whether the wound is to be closed or not? My position is that it is of no use at this time, because if the operation has been thoroughly done there are so few bacteria left behind that it is extremely unlikely that any growths will be obtained. In such a case the surgeon will perform a primary closure, or not, depending upon the anatomic difficulties, or such other factors as he may consider. When the bacteriologist is present at such an operation he may take direct cultures from the infected tissues *in situ*, or after their removal, as well as from foreign bodies, for the purpose of determining the original infection. Such knowledge is of more value to him than it is to the surgeon.

We now come to what I consider to be the most favorable time for taking cultures and smears for bacterial counts. I believe that if the surgeon decides to perform a primary closure, the *ideal* method is to place at the most dependent part of the wound a few strands of silkworm-gut or horsehair, leading to the deepest part of the wound. At the first dressing, which should be done within twenty-four hours, these should be removed by the surgeon, the bacteriologist being present, if possible. There follows their removal the escape of a certain amount of serum which will most certainly be infected if bacteria have been left behind after operation. From this serum the bacteriologist will be able to secure his cultures and smears. A stained smear will show the presence or absence of bacteria, and, in the presence of such evidence, the surgeon can very shortly decide whether the wound should be immediately reopened or not. On the other hand, he may decide, on the clinical condition of the wound, to await the result of the cultures before reopening.

It has been objected by some surgeons that it is unwise to introduce a foreign element into an otherwise aseptic and firmly closed wound, with the formation of a sinus, however small, resulting from the removal of the strands. It is my firm belief that the chances of infecting secondarily such a wound are much overbalanced by the element of safety thus obtained. In the hands of surgeons who have had wide experience the progress of such wounds may be at times determined by the clinical picture, but I have known of several cases which have had to be reopened, with streptococcal infection, under such conditions. In consideration of the varying ability and amount of experience of our surgeons, I believe that the procedure outlined above will be a safer routine to follow than to depend on clinical evidence alone.

I have said above that I consider this to be the *ideal* method. It has been followed in a certain number of cases with very good results. There have been a large number of cases of primary closure, on the other hand,

which have been entirely successful without any bacteriologic control. The surgeons were, however, men of unusual experience in the treatment of war wounds, and this must be borne in mind in deciding on the merits of the two methods.

If, for one reason or another, the wound is not closed at the original operation, a culture and smear taken at the first dressing will give the surgeon such information as will allow him to perform a delayed primary closure, or not, as he may decide.

It is, of course, evident that the preceding remarks apply only to cases of very recent injury, where infection has not had sufficient time to become well established. A large number of cases are of such a nature. There are, however, many cases in which the time that elapses between injury and the patient's arrival in the hands of the surgeon is much longer. Here we have infection well established on arrival. There are also many cases where the infection is of a rapidly spreading or fulminating type. In both instances it is very doubtful whether the surgeon would consider himself justified in performing a complete operation of débridement and excision. He would then clean up the wound as much as possible and establish some form of irrigation, such as Carrel's method. Here, then, the original infection of the wound persists, and it is of the utmost importance for him to know what the infection is, both aërobic and anaërobic. In such a case cultures are taken from the most likely looking foci of infection.

PROCEDURE FOR BACTERIOLOGIC EXAMINATION OF WAR WOUNDS

For such an examination one should employ all the aids which may lead to a correct diagnosis of the bacteriologic condition. These are (not in order of importance) the hanging-drop, the stained smear on a glass slide, aërobic and anaërobic cultures, and the leukocytic index.

The hanging-drop reveals the presence or absence in the original exudate, or a later liquid culture-medium, of cocci, in chains or not, and of bacilli. The presence or absence of motility and of spores in the latter should be noted. The technic and significance will be discussed later.

The stained smear on a glass slide for the bacterial count not only for the relative number but for the relative proportion, between cocci and bacilli, is of great importance.

In wound bacteriology, quite differently from that of ordinary civil practice, we are obliged to consider the possible or even probable presence of anaërobic in addition to aërobic bacteria in the large proportion of cases. For this reason we are obliged to adopt a special technic in securing our cultures. These may be taken with the Pasteur glass pipet, the platinum loop, or by cotton swabs. By far the best method for the majority of cases is that of the pipet. With the pipet one obtains a homogeneous amount of exudate, serum, or pus, which can never be true, to the same extent, with the loop or the swab. This is important for the reason that not only cultures but also smears and hanging-drops should be secured from the same specimen of exudate. The pipet has the further advantage that when the specimen has been

secured the pipet may be sealed at the tip, and then taken back to the laboratory, where it may be examined at leisure.

In using the platinum loop the different culture-media must be inoculated separately, and the smear made with another loopful. The same is true of the hanging-drop. This method is not recommended.

The use of the swabs precludes the examination of the direct hanging-drop, but otherwise is of value. It does not compare, however, with the pipet for most cases. There are some cases in which, from the location of the wound and the condition of the patient, the pipet cannot be used, and here the swabs are useful. There are times, also, when the surgeon prefers to take his own cultures, from his knowledge of the intricacies of the wound, and a desire to prevent possible infection of the adjacent healthy tissue, and in such a case he should use the swab. In times of activity when several surgical teams are working at the same time, it is obviously impossible for the bacteriologist to be present at each case. The same is true when the cases are being subsequently dressed. At such times the wounds cannot be exposed for a long time awaiting the arrival of the bacteriologist, and the surgeon or his assistant may then take the cultures with swabs, which should be sent immediately to the laboratory. These methods as well as those for the determining of the leukocytic index will also be discussed later.

The Hanging-drop.—The information secured from the hanging-drop from the original, or later exudates, or from a fluid culture-medium may be of great importance. If taken for the academic value of determining the original infection, or as a guide to the advisability of a primary closure, the information will depend largely on the length of time that has elapsed since the wound was received. In the first ten hours, as has been said, there is usually very little proliferation of bacteria, but there may be enough to be of definite assistance. Beyond this time growth is usually well assured.

The generally accepted opinion is that the hanging-drop is greatly superior to the method of placing a drop on a slide and covering it with a cover-slip. If cocci are present in chains they can be seen better in their original state. For the determination of motility in bacilli, especially the anaërobes, there is no comparison. I have made many comparative examinations with the flat slide and the hanging-drop from the same exudates and fluid media, and have found the motility much more marked in the hanging-drop. The hanging-drop is very easily made, and takes very little more time than the other. The presence of cocci in chains is significant, but it must by no means be assumed that they are pathogenic streptococci. If present, however, the surgeon should be immediately notified, so that he may be on his guard until the result of the cultures is known. The presence of bacilli, motile or not, spore-bearing or not, should be told the surgeon also. This preliminary information is of value, but is not necessarily conclusive.

As regards motility of bacilli, particularly the anaërobes, it may be said that this varies so greatly, even in specimens of the same species,

according to their environment and conditions of growth, that a positive statement must always be guarded against. The examination of the sealed capillary tube may here be of value. A pipet is drawn out into a rather fine capillary length. A bit of the exudate is drawn up into the capillary portion, which is sealed at the tip and just above the fluid. Under such anaërobic conditions motility will frequently be observed, where it was absent in a hanging-drop from the same specimen.

The Stained Smear.—The value of the stained smear for the determination of the bacterial count, as advocated by Carrel, and the bacterial index has been the subject of much controversy. I believe that it has a great deal of value when the results are correctly interpreted. By this I mean that the results must be taken as a relative index, and not as a definite numeric entity. The objection has been frequently raised, and properly so, that it is impossible always to obtain smears of the same uniformity, and thus the readings will constantly vary. As a matter of fact, this objection has been shown to be more or less theoretic. A series of smears of varying density from the same specimen show a striking similarity in the count, especially when the number of bacteria present is very low or very high per field. It is quite true that in the intermediate ranges the counts will vary to a greater or less degree. Fortunately, we are more concerned about the low counts, as here it is a question of the advisability of closing the wounds. When the count is high, anywhere from 20 per field to infinity, we know that the wound cannot safely be closed, regardless of what the cultures may show. But a series of counts, every day or every other day, showing a steady diminution in the number, is evidence that the infection is diminishing and that the wound may soon be in condition to close, other factors being favorable.

It has sometimes been stated that a clean-appearing wound may be closed on the clinical appearance alone. This is not always true, as many lamentable failures have shown. It is frequently apparent that wounds infected with virulent streptococci present a very clean appearance, especially when they have been treated by Carrel's method, thus altering the natural appearance of the wounds.

It has been urged against the necessity of following wounds by bacterial counts that when a wound appears to be ready for closure it requires only a negative culture, or series of cultures, to confirm this belief. These should be secured in any event before the closure is made, even when the bacterial counts are also made. Many times a few bacteria in a wound will give profuse growths in the cultures, and we thus have no guide as to the number in the wound unless the bacterial counts are made. On the other hand, a series of low counts, while the cultures show no hemolyzing cocci or anaërobic bacilli, is a direct bacteriologic indication for closure.

It has also been objected that, in the course of treatment, the count of one day may at times show a great increase over that of the previous day, and thus is of no value. My observation of such cases leads me to the conclusion that usually such a sudden increase is due to a break

somewhere in the Carrel technic, especially in the application of the dressings.

The process of making the smear and determining the number of bacteria per field is easily and very quickly done. It is an important aid, though not conclusive in itself, and should always be adopted as part of the routine. In addition to the count, the bacterial index, or the proportion of cocci to bacilli, is always of interest, but not necessarily important. This can be very easily determined while the count is being made.

Technic.—If the smear is to be made from a case before irrigation is instituted, the exudate may be taken directly from the wound, care being used not to take up free or clotted blood if it can be avoided. If irrigation has been begun, it should be suspended for at least two hours before the examination is made. Carrel has indicated that the bacteria found on a smear from an exudate may not be the same as those which will grow in the cultures. We may also find dead bacteria or living organisms which will not find in the wound the necessary conditions for development.

The specimen may be taken either by a pipet, platinum loop, or a cotton swab, but it should be taken from all parts of the wound. If taken with a pipet or loop, a drop should be placed on a glass slide. It may then be spread either with the end of the pipet or a sterile cotton swab. The best smears are made with the swab. The exudate should be spread in lines parallel to and touching each other, but these *should not overlap, and the same area should not be gone over twice.* This is an important point if one wishes to obtain any uniformity in the smears. The method of placing a cleaned and flamed slide on the surface of a superficial wound cannot be recommended, and would probably be frowned upon by most surgeons. The slides should be dried in the air and may be fixed by heat in the usual manner, unless they are to be examined also for the leukocytic index, which will be described later. The first slide from a case should always be stained by Gram to show the possible presence of anaërobic bacilli, which are practically always Gram-positive. Later, when the cultures have given the required information concerning the anaërobes, the slides may be stained by some more rapid and simple method. Nicolle's method gives very good results. The slide is covered with carbol-thionin and held over a flame until it begins to steam. The stain is then washed off and a counter-stain of saffranin is applied for a few seconds. The bacteria alone are stained dark blue, while the cells are stained pink. In using the Gram it sometimes happens that the carbol-gentian-violet or the anilin-gentian-violet are not properly made. We may then be confused by the presence of very fine stained droplets which may be mistaken for cocci. The irregularity in size will usually be sufficient to distinguish them.

Some time ago I observed in several cases, where the count should theoretically have been low, what appeared to be a count of infinity of cocci in every field. They were all of approximately the same size.

Fresh stains were made up, but the results were the same. On inquiry, the cases were all found to be suffering from surgical shock. At about the same time, at autopsies performed on cases dying in extreme shock, it was demonstrated that the blood contained an enormous amount of free fat. It immediately occurred to me that we were dealing with the same condition here. The cultures proved to be negative or nearly so, and the fat-droplets disappeared as the cases improved. So far as I am aware, this condition seen on the slides has not been described before. Whether the presence of these fat-droplets in blood-smears from cases of surgical shock, with their relative enumeration, might be of any value in the study of shock is an interesting question which might be considered. In these cases the swabs were taken from the depths of wounds, where it was fairly safe to assume that the fat was not extravasated directly from the subcutaneous tissues or from bone-marrow.

Many smears from wounds in cases suffering from extreme surgical shock were examined. The smears on sterile glass slides were fixed in formalin vapor for forty-five minutes. Part of them were then subjected to the solvent action of either ether or xylol for fifteen minutes. All of the slides were then stained either with sudan III or neutral red. The slides untreated by a fat solvent showed the presence of large amounts of small red-stained fat-droplets, while those treated as described above showed no red-stained fat.

Sections of lung tissue taken from cases dying from shock were examined by Captain Wayne W. Bissell, Pathologist to Evacuation Hospital No. 1. These showed the presence of great amounts of fat, stained by sudan III, in the blood-vessels.

Another source of confusion occasionally encountered in the presence of minute, apparently stained droplets from another source. Part of the technic for the Carrel treatment consists in the placing of strips of gauze impregnated with sterile vaselin about the margins of the wound, to protect the surrounding skin from action of the Dakin's solution. Some of this vaselin at times is introduced into the wound and may be picked up by the swab and thus transferred to the slide. We may then find these minute apparently stained droplets, which may be mistaken either for cocci or for deposits, in the stain. This possibility should be borne in mind.

The method of making a bacterial count should be, and probably is, perfectly familiar to all of our bacteriologists. At our hospital we were accustomed not only to make the counts but also to consult with the surgeons as to the advisability of closing the wounds. We were very frequently asked if it were safe to close a wound on the evidence of the smears and cultures, other factors being favorable. Our advice was, usually, that if the count shows one bacterium in two fields or less, for two or three successive counts, and the cultures show no hemolyzing cocci and very few anaërobic bacilli, the wound may be closed. We have occasionally advised closure where it was most important that it should be done as soon as possible when the count showed 4 per field. Here, however, the cultures showed one or two small colonies

containing non-pathogenic diplococci. Fortunately, these cases all healed perfectly, but such advice should only be given in cases of great necessity, and under careful watching by the surgeon. As was stated above, no wound should be closed on the advice of the bacteriologist until the low counts have been confirmed by negative cultures, or cultures showing only a rare colony of non-hemolyzing cocci, and very few anaërobic bacilli.

The Leukocytic Index.—The examination of the smear for the determination of the leukocytic index is considered not because it is of great importance, but as another aid which might be used in an otherwise puzzling case. The smear is made in the usual way from the exudate or pus, but is fixed and stained as for an ordinary differential leukocytic count. The percentage is taken, among the leukocytes counted, of the polynuclear and the mononuclear cells. In the early stages of infection the polynuclears predominate very largely, but, as the infection is overcome, the mononuclears appear in ever-increasing numbers. This has been a well-known fact for a long time. As a matter of fact, the information thus obtained goes very well in hand with the bacterial counts. Its chief value is to serve more or less as a check upon the counts. For ordinary routine work this procedure is unnecessary. The same is true of the method of vital staining of leukocytes, and the determining of pyknosis and phagocytosis as described by several writers. They are of interest when one is not busy, but they may be dispensed with.

Cultures.—The routine culture-media used at our hospital were of two kinds, a fluid culture-medium of some sort, with an agar slant for the aërobes, and litmus milk with Veillon's deep agar for the anaërobes. From the original cultures any cocci found were transplanted to blood-agar, as will be described later. Our first fluid medium was ordinary broth in which grew not only most of the common aërobes, but most of the anaërobes as well. It was then found that a medium should be used in which a more rapid growth of streptococci might be obtained. For several months we used Weissenbach's medium, made as follows:

Prepare separately the two following solutions:

1. Glucose peptone water:

Water	100 c.c.
Peptone	4 gm.
Salt	0.5 gm.

Make slightly alkaline to litmus paper. Autoclave fifteen minutes at 120° C. to precipitate. Filter, and add for 100 c.c. of the solution, glucose 0.2 gm. (Chemically pure glucose not necessary.)

2. Alkaline egg albumin:

White of egg	1 part	in c.c.
Distilled water	3 parts	

Two whites of egg give from 200 to 250 c.c. of mixture. Mix and beat up in a large glass or bowl. Add 0.5 c.c. of 10 per cent. solution of sodium hydroxid for each 100 c.c. of the mixture. Autoclave for fifteen minutes at 115° C. to precipitate. Filter while hot.

Mix the two preceding solutions (1 and 2) 50 c.c. of each.

Divide into test-tubes, 5 c.c. in each. Sterilize in autoclave fifteen minutes at 110° C.

In this medium streptococci will outgrow any other bacteria except staphylococci, and should be found, if present, in four to eight hours. Many of the anaërobes will also grow in this medium. For the routine growth or isolation of anaërobic bacilli there are, of course, many other culture-media that may be used, particularly those containing meat in one form or another.

More recently we used for routine work a modification of a culture-medium suggested by Major Benjamin Jablons, M. C., Central Medical Department Laboratory. This consists of peptone 10 gm., sodium chlorid 5 gm., water 1000 c.c., alkalinized with normal sodium hydroxid solution to a reaction of —3. This peptone water is distributed in test-tubes, 5 c.c. in each, and to each tube is added a small piece of sterile rabbit liver. The tubes are then autoclaved in the usual manner, after which titration usually shows an alkalinity of about —0.5.

Owing to the difficulty in obtaining rabbit liver we used beef liver. As this seems to produce more acidity, we titrated our peptone water to an alkalinity of —3.5, which gave an end-result of —0.5. We also put from 8 to 10 c.c. of the solution into each test-tube. This is an extremely simple medium to make, and is very satisfactory. Streptococci seem to grow in it as quickly as in Weissenbach's medium, and, in addition, the anaërobic bacilli grow profusely. It is used in all respects as is Weissenbach's, and we found it more satisfactory for routine work.

The method of inoculating the different media depends on whether one uses the pipet or swab.

The Pipet Method.—Specimens should be secured from wound exudates as free from blood as possible. Where gas bacillus infection is already established, the exudate should be taken not only from the muscle in the depths of the wound but also from the borders where the infection seems to be spreading, and from the edema, if present. Occasionally, in severe cases of gas bacillus infection, there are bullæ present in the skin over or near the process. These contain a serous exudate in which are found large numbers of the bacteria. The surface should be seared with a hot knife or glass rod, punctured, and the exudate drawn into the pipet.

PROPERTY OF SURGICAL OFFICE NOT TO BE REMOVED

A hanging-drop and stained smears should be first examined, and the results noted. Before proceeding to inoculate the media the broth, if used, and litmus milk should be regenerated by boiling for fifteen minutes and the air driven out, and then cooled to 40° C. or lower. It is not necessary to heat the Weissenbach medium or the liver-peptone solution. Several tubes of Veillon's agar (agar containing 0.2 per cent. each of glucose and sodium nitrate) are boiled at the same time to drive out the air, and held at a temperature of not less than 42° C. until inoculated. Everything being then in readiness, a tube of broth or, better, the liver-peptone water medium, an agar slant, and a tube of litmus milk are each inoculated with 1 drop of exudate, successively. Two, three, or more tubes of Veillon's agar are then used. The remaining exudate in the pipet is inoculated into the first tube, and successive dilutions are made into the remaining tubes. Each is thoroughly rolled

between the hands, and then rapidly cooled by being placed in cold water. A small spatulaful of sterilized calcium sulphid is dropped into the tube of litmus milk, and upon the solidified agar in each tube. To make the spatula I have hammered out the end of an iron wire, such as we use for making swabs, and take what this small spatula will hold. The wire is sterilized by passing through a flame several times before using.

In addition, sterile liquid petrolatum is overlaid on the milk, about 1 cm. in depth. The calcium sulphid absorbs oxygen, and the liquid petrolatum retards the further access of oxygen. The media are then placed in the incubator.

At the end of four, six, or eight hours the tube of Weissenbach's medium or liver-peptone solution should be examined. If there is no apparent growth, it may be left longer in the incubator. If some growth is visible, particularly a granular deposit, a small amount of the fluid from the bottom of the tube should be taken up with a sterile pipet and a hanging-drop made. If cocci in chains are found, a smear should also be made and stained by Gram in order to confirm the hanging-drop. Cocci in chains having been found, a subculture is made on a blood-agar plate to determine whether they are hemolytic or not. By this method the presence of hemolyzing streptococci should be demonstrated by the following morning.

I have used a method here which gives even better results in a large number of cases. Before inoculating the liver-peptone water medium the patient's finger-tip is sterilized with tincture of iodin, pricked, and a drop or two of blood is transferred to the medium by a sterile pipet. In a considerable number of cases the presence of cocci in chains alone, together with hemolysis of the blood, has been demonstrated on the same day, allowing a positive diagnosis of hemolyzing streptococci to be made. Many of these cases have been controlled by finding hemolyzing streptococci in blood-agar plates from the same culture. When hemolyzing staphylococci or bacilli are also present a source of confusion is introduced which must be controlled. If the medium is examined at an early hour the cocci will be found before the bacilli have had time to develop. Otherwise a subculture on blood-agar must be made. If both streptococci and staphylococci are present they must be subcultured on a blood-agar plate to determine which is the hemolyzing organism, or if both cause hemolysis.

For routine work in a busy hospital I believe that the streak blood-agar plate method is superior to the pour-plate. It is very easy to keep twenty or thirty plates constantly made up, and the consequent saving of time is considerable. We have made parallel series of cultures by the two methods, and have found no remarkable difference between them, so far as reliability is concerned.

In using the pipet, which is furnished with a rubber tube, the sealed tip is broken off, and the capillary portion is sterilized on the outer surface by passing it several times slowly through a flame, gradually revolving it so that all portions of the surface are equally sterilized. As

the whole pipet has been previously sterilized, it may be assumed that the interior is also sterile. When only a small amount of exudate is secured, not enough for all the procedures already mentioned, it was our custom to inoculate all of it into a tube of liver-peptone water. After three or four hours in the incubator, during which time both the aërobes and the anaërobes develop, the other media may be inoculated from this, as described above. In such a case, however, it is best to use the swab method.

The Swab Method.—Two swabs are placed in each agglutination tube, and the whole tube is sterilized. In taking cultures the swabs are removed together and used as a single swab, in order that we may obtain as uniform a specimen as possible. On arrival at the laboratory a smear is made with one of the two swabs, a tube of liver-peptone water is inoculated, and then a tube, or more, of Veillon's agar. If the amount of exudate is profuse, the first Veillon's agar tube is inoculated, and dilutions made from this into as many others as may be desired with a platinum loop. If the exudate is scanty, one tube only is inoculated, and sometimes the swab is left in the tube. With the second swab a slant agar tube and one of litmus milk are inoculated. In this case, if the exudate be scanty, the swab may be left in the litmus milk tube. The subsequent procedures are the same, whether one uses the pipet or the swab. A possible element of doubt may enter here. It may be contended that in making the smear, even though on a slide just cleaned and sterilized by passage through a flame several times, bacteria from the air or other sources may be introduced into the smear, and, in turn, into the culture-medium. This seems to me a very remote chance, and I have yet to see a case where it seemed at all likely. It is mentioned to forestall the question which might arise.

If pieces of devitalized tissue, particles of clothing, etc., from the track of the projectile are taken, they may be inoculated directly into the different media. The missile itself or other single foreign body, if not too large, should be introduced directly into a tube of liver-peptone water medium, incubated for three or four hours, and then the other media may be inoculated from this.

A considerable amount of information may be obtained from the litmus milk. If the B. welchii is present a large proportion of cases will show a beginning stormy gaseous acid fermentation in from six to eight hours. If they are few in number, on the other hand, this reaction may not appear for twenty-four hours or longer. Also, if we have anaërobic bacilli belonging to the proteolytic group, we may see proteolysis beginning in a few hours, although this process is usually of slower onset.

Isolation of Anaërobic Bacilli.—An approximate diagnosis of the variety or varieties of the anaërobic bacilli may be made at times upon the cultural characteristics, together with the morphologic characteristics, as shown in the stained smear and the hanging-drop, or the capillary tube. For a complete determination of the species, however, we must come to agglutination tests, neutralization of toxins, or animal inoculations for pathogenicity. It has been shown by several writers that spore forma-

tion and motility vary so much in different strains of the same bacilli, and in the same strains under different conditions of environment, that they cannot be depended upon as safe guides in making a diagnosis as to the species. To make such a complete diagnosis requires more equipment than is available in the average evacuation or base hospital, and such cultures should be sent to the Central Medical Department Laboratory. For routine work enough information can be obtained by the means at our disposal to be of service to the surgeon, and we will now consider such means.

It is obvious that, in order to arrive at any approximate knowledge of the bacilli with which we are dealing, we must have pure cultures. For this technic the use of the pipet is indispensable. In a large proportion of the cases it will be found that we are dealing with two or more different varieties of bacilli, as shown not only in the smear and hanging-drop but also by examination with a hand-lens and the lower power of the microscope of the colonies in the tubes of Veillon's agar. In the first tube, if the growth is profuse at the end of twenty-four hours, we shall see a great number of colonies with or without production of gas and fragmentation of the medium. In the succeeding dilutions we shall see fewer and fewer colonies, with less or no gas, until in the last dilution, if enough tubes have been used, there will be found only rare or single discrete colonies which will present characteristic appearances. Roughly speaking, the colonies formed by motile bacilli are of the arborescent type, while those formed by non-motile bacilli are of the lenticular or heart-shaped type. It should be stated at once that this is purely approximate, as we may find all sorts of combinations of the two types in apparently pure cultures, depending somewhat upon the degree of motility present under the existing conditions of growth. Changes in the composition of Veillon's agar will also show quite different appearances of colonies from the same organism.

It sometimes happens that we have cases in which the tubes of Veillon's agar show colonies which are apparently all of the same type and are identical in appearance. Our procedure is then much simplified. A line is filed across the side of a tube showing a few colonies, about $\frac{1}{2}$ cm. above the colony we wish to secure. By holding the sharp tip of a glass rod, heated red-hot in the flame, against the filed line the tube will be cracked in a circular line. The agar may be divided across at the same line. With a pipet, sterilized as described above, the agar is penetrated down to the colony selected, which is then aspirated into the pipet. This is then transferred into liquid culture-media. I have been accustomed to use, as far as possible, the method taught me by Dr. Weinberg, of the Pasteur Institute, who uses freshly boiled broth containing 0.2 per cent. glucose, and broth containing a piece of hard-boiled white of egg, about $\frac{1}{2}$ cm. cube. It is essential to secure as perfect anaërobic conditions for growth as possible. In the absence of a vacuum-pump, by which the air in the tubes is withdrawn, we are accustomed to use calcium sulphid and liquid petrolatum as described above (p. 358). In the tubes containing the hard white of egg we ob-

tain a more free development of spores, and, in addition, the proteolytic action of the bacteria upon the white of egg is shown, if present.

At the end of twenty-four hours the broth cultures are examined for the presence of motility and spores. Smears may also be stained by the Hiss stain for capsules, and by van Ermengem's stain for flagella if desired. Agglutination tests may then be made with the broth emulsions against the various agglutinating sera. Certain species of anaërobic bacilli, such as the B. œdematiens, appear at times to be auto-agglutinating, and, in such a case, we must resort to neutralizing of toxins by antitoxic sera, or to pathogenicity experiments, to arrive at a final identification. For the ordinary routine work, however, such refinements are unnecessary.

Where we have two or more anaërobes present, as shown by the hanging-drop and smear, as well as by different types of colonies in the deep agar, our procedure becomes more complicated. It is then necessary to pick out one or more colonies of each type to be transferred to broth. Here we may have to inoculate a number of tubes of agar, unless we are fortunate enough to find single colonies of each type in our first cultures. The procedure from this point is as described above. It is sometimes an aid, in securing single colonies, to use a Vignal tube. This is a glass tube plugged with cotton at both ends and sterilized. The tube is drawn out into a constricted neck near one end, and the other end is drawn out into a short capillary portion, as in making the ordinary pipet. A tube of Veillon's agar is inoculated, and well mixed by rolling between the hands, and before it is cooled some of the agar is aspirated into the Vignal tube, with a fitted rubber tube, up to the constriction. The tube is sealed at the end and at the constriction, and rapidly cooled. It is then incubated under almost perfect anaërobic conditions. The colonies to be examined can be obtained by filing and breaking the tube as already described. If gas has developed, however, it is necessary to break off one end first to relieve the pressure, otherwise most of the medium may blow out when the tube is cracked across.

When we have a mixture of spore-bearing bacilli and non-spore-bearing organisms we may secure a pure growth of the spore-bearers by inoculating the deep agar while it is at a temperature of 90° to 95° F., and holding it there for ten to fifteen minutes.

Blood-cultures should be made in cases in which infection with anaërobic bacilli is suspected, as well as streptococcus or staphylococcus infection. The blood should be taken in the usual way from a vein in the bend of the elbow. From 1 to 5 c.c. may be inoculated into each of several tubes of melted deep agar and freshly boiled broth. After the tubes of deep agar have been rapidly cooled, calcium sulphid should be dropped on the surface of each. Calcium sulphid should also be dropped into the tubes of broth, which are then overlaid with the liquid petrolatum. Blood-cultures for streptococcus or staphylococcus infection should be made in the usual manner.

Examination of Cultures.—In the examination of cultures from war wounds we find a flora which may be, and very likely is, present in

some wounds seen in civil practice, but in such wounds we have not been in the habit of paying them much attention, regarding them simply as contamination organisms. This is particularly true of the anaërobic bacilli, but hardly less so of some of the aërobic organisms commonly found. I will first mention some of the organisms commonly found and then discuss their characteristics and significance in war wounds.

Aërobes.	*Anaërobic Bacilli.*
Streptococcus.	Bac. welchii (perfringens).
Staphylococcus.	Vibrion septique.
Enterococcus.	Bac. sporogenes.
Diplococcus griseus non liquefaciens.	Bac. tertius (H. Henry).
Pneumococcus.	Bac. fallax (Weinberg and Séguin).
Micrococcus candidus.	Bac. putrificus.
Bac. proteus.	Bac. bifermentans.
Bac. coli.	
Bac. Friedländer.	
Bac. anthracoides.	
Bac. mesentericus.	Bac. œdematiens (W. and S.).
Bac. subtilis group.	Bac. histolyticus (W. and S.).
Bac. pseudodiphtheriæ.	
Bac. cutis communis.	

Aërobes.—In the presence of cocci in war wounds we are immediately confronted with many confusing factors. We find cocci in pairs, in groups, and in chains under so many different conditions and combinations that at first it seems impossible to make any clear differentiation. This applies not only to cocci as found in cultures but also to cocci as seen in the smear and hanging-drop. It has been our custom to call as streptococci only such chain-forming cocci as produce hemolysis in blood (S. hæmolysans). All others, with the exception of S. viridans, we designate as "cocci in chains." It should be understood, of course, that this is purely a local nomenclature. Staphylococci, other than S. aureus, we speak of as "cocci in groups."

On examination of young cultures, then, both in the liver-peptone water and on the agar slant, from the great majority of war wounds showing a positive growth, we find cocci single, in pairs, in groups, or in chains. The hemolyzing cocci we assume, in the absence of contradictory evidence, to be virulent, while the non-hemolyzing cocci are not virulent, and act in the wound simply as saprophytes. Under what species may we classify the non-hemolyzing cocci? It has been found that all the varieties of cocci mentioned in our list may, at different periods of their growth and under different conditions of growth, appear singly, in pairs, in groups, or in chains. Furthermore, of the two elements of a diplococcus, both may be alike, one may be round, while the other may be lance shaped, or of an elongated form simulating a bacillus. In fact, all the different combinations may be seen at times.

They may also be encapsulated or not. We will consider first the three varieties which we are continually finding, and endeavor to differentiate them: Enterococcus, Streptococcus, and Diplococcus griseus non liquefaciens. Microscopically they may be, and usually are, identical in young cultures. Culturally, Tissier[1] has tabulated their characteristics as follows:

Enterococcus. Uniform turbidity in broth, with a mucous deposit rising in corkscrew form on shaking. On solid media it forms a bluish transparent film with clearly defined borders. It grows well on gelatin at 20° C. and on potato. It coagulates milk, giving a soft granular clot. It ferments all the sugars, growth being arrested by an acidity of 2 to 2.45 per 1000. Does not hemolyze blood.

Streptococcus. No turbidity in broth, but forms a granular deposit in the bottom of the tube. On solid media the colonies are separated, with raised centers and crenelated borders. Does not grow on potato, and very poorly on gelatin at 20° C. Coagulates milk, giving a hard, laterally contracted clot. Ferments the sugars except mannite. Growth stopped by an acidity of 1.47 to 2 per 1000. In twelve hours it hemolyzes ordinary blood-broth medium.

Diplococcus griseus non liquefaciens. Slight turbidity with very fine granular deposit. On agar the colonies are fine and separated, with very slightly raised borders. Does not grow on potato, and only slightly on gelatin at 20° C. Does not coagulate milk. Of all the sugars, only glucose is fermented, and this only slightly. Growth stopped by an acidity of less than 1 per 1000. Does not hemolyze blood.

This tabulation, so far as the streptococcus especially is concerned, does not correspond in many respects with the more recent descriptions of the organism that have been given, but it was thought that, in a general way, the three varieties might be thus differentiated.

The great majority of cases of our war wounds show the presence, in cultures, of diplococci, either as such, or arranged in groups or in chains. This arrangement of cocci in pairs can be very easily recognized, and seems to be nearly universal, regardless of the species to which they may belong. For this reason we transplant all cocci present to blood-media, to determine the presence or absence of hemolytic streptococci or staphylococci. The remaining cocci, while not virulent in themselves, may favor the development of the anaërobic bacilli. The problem of symbiosis arising here offers a field for much investigation.

Aside from streptococci and staphylococci, which may be distinguished by their hemolyzing action on blood, we see that the enterococcus and the Diplococcus griseus may present similar morphologic characteristics. Dr. Legroux, of the Pasteur Institute, believes that they may be forms of avirulent pneumococci. It is possible that a study of their behavior toward bile might throw more light on the subject. I have as yet made no attempt to classify the various strains of streptococci found, with the exception of the Streptococcus viridans. I have found this organism three times, once in pure growth from a

blood-culture. The Micrococcus candidus appears to be a variety of the Staphylococcus albus, probably the same as the Staphylococcus epidermidis albus. As compared with wounds in civil practice, where the Staphylococcus aureus is, perhaps, the organism most frequently found, it has been noticed that it is comparatively seldom found in fresh wounds. Most of the staphylococci found seem to be skin cocci, so-called. Enterococci and the Diplococcus griseus are facultative anaërobes, and at times grow in a thick cloud of fine lenticular colonies throughout deep agar. This is a source of great annoyance, making it very difficult to pick out colonies of the anaërobic bacilli.

The aërobic bacilli found in war wounds are many, some varieties of which appear to be rare in wounds encountered in civil practice. Legroux[2] has stated that the aërobic bacteria most frequently seen in fresh war wounds are four in number: Streptococci, staphylococci, Bacillus pyocyaneus, and the bacillus of Friedländer. This has not been my experience, but it is quite possible that the flora of one region may be quite different from those of other regions. This may be accounted for by many different factors, such as the character of the soil and the conditions and degree of cultivation.

The *Bacillus proteus* is a very common organism in war wounds. It produces foul-smelling and filthy wounds, and is extremely difficult to eradicate. Owing to its rapidly spreading growth in cultures it makes the isolation of other bacteria a matter of considerable trouble. It is a facultative anaërobe, producing gas, and sometimes fragmentation, in deep agar. Its cultural and morphologic characteristics are too well known to require further comment.

The *Bacillus coli* is occasionally seen, and presents nothing of new interest, morphologically or culturally.

The *Bacillus pyocyaneus* is quite often encountered, but I have yet to see it in a fresh wound. The earliest date of its appearance in any of our cases was six days after the injury. It is difficult to free wounds from this organism, and when one case appears in a ward the neighboring cases appear to be extremely liable to the same infection. The bacillus is well known and needs no further consideration.

The *Bacillus of Friedländer* or other members of the B. mucosus encapsulatus group. were found by us in only a small proportion of the cases. They present no points of especial interest.

The *Bacillus anthracoides* is frequently found. On the slant agar the colonies are flat, grayish white, rather wrinkled on the surface, and usually 2 to 3 mm. in diameter. The bacilli are similar in form and dimension to the B. welchii, non-motile, occasionally producing spores, and are Gram-positive. They are apparently non-pathogenic. As seen in the smear and hanging-drop they may be mistaken for anaërobic bacilli, but they are pure aërobes.

The *Bacillus mesentericus* is also a fairly common organism. It is Gram-positive and motile, produces spores, and will not grow under anaërobic conditions. The colonies on agar slant are somewhat similar to those of the B. anthracoides, but the surface is more corrugated.

The stained bacillus is long and very broad, granular, and presents many minute unstained areas like vacuoles, and is very characteristic. This bacillus is apparently non-pathogenic.

Bacilli of the *subtilis group* are extremely common. The colonies are usually rapidly spreading on the surface of the agar slant, grayish white in color. The bacilli are long and rather thick, Gram-positive, and quite motile in young cultures. Spores are frequently seen. No pathogenicity has been observed.

The *Bacillus pseudodiphtheriæ* and the *Bacillus cutis communis* are practically identical, although the B. cutis communis is usually seen as a shorter bacillus. They are found in a large number of cases, but do not commonly appear for several days. In another hospital out of 1000 cultures from old wounds I found one or the other variety present in 32 per cent. They are Gram-positive and non-pathogenic.

Anaërobic Bacilli.—I do not consider it necessary, in the present discussion of war wounds, to go into a detailed history of the various anaërobic bacilli, although this is of extreme interest. This subject is fully dealt with in the admirable and exhaustive book, La Gangrène Gazeuse, by Weinberg and Séguin, recently published. It will be enough for our purposes to mention the essential characteristics of the bacilli which we have found to be present in the wounds we have examined. Some of the French writers have attempted to classify the bacilli according to their motility, taking the B. welchii as a type of non-motile and the Vibrion septique as a type of motile bacilli. Some of the English observers, on the other hand, classify them according to their proteolytic powers. As we are not concerned at present with the need of such classification, it will not be discussed.

Bacillus Welchii.—This bacillus, known also as B. aërogenes capsulatus or the B. perfringens, is found more frequently than any other, both in the smear and the culture. It occurs usually as a short, thick Gram-positive rod, with slightly rounded ends. Sometimes they occur in pairs, end to end. The bacillus is strictly non-motile. In some specimens a capsule is present, while others show none. In the hanging-drop features suggesting a capsule may be observed at times, showing as a white margin by raising and lowering the condenser. Some strains are said to be spore bearing, but we have never met them under conditions suggested for their development. In broth with 0.2 per cent. glucose, or in plain broth with a cube of white of egg, there is a turbid growth with considerable gas production. When litmus has been added to the glucose broth there is found to be an acid reaction in a previously alkaline medium. The culture gives off an odor of butyric acid. In Veillon's agar there is much gas formation and fragmentation of the medium. The colonies, as examined under the hand lens or the low power of the microscope, present some characteristic features. These are usually lens shaped or heart shaped at first, but later may show small outgrowths from one or both sides of the lens, or from the cleft of the heart. In litmus milk there is developed an acid, stormy, gaseous fermentation, which is characteristic. If the bacilli are few

in number in the culture, this reaction may be delayed beyond twenty-four hours. It is generally agreed that the white of egg in broth does not show proteolysis except in rare instances. I have not studied the saccharolytic properties of any of the anaërobic bacilli nor their pathogenic powers.

For all practical purposes this bacillus may be identified by its morphologic characteristics, both in the stained smear and the hanging-drop, as a Gram-positive, non-motile, and usually non-spore-bearing, short, thick rod, sometimes encapsulated, in addition to the characteristic growth in Veillon's agar and litmus milk We did not secure any agglutinating serum for purposes of identification.

Vibrion Septique.—This is a Gram-positive bacillus found very frequently in war wounds. It is of variable dimensions as to length, but is not as thick as the B. welchii. The ends are well rounded. It is motile, with a rolling or tumbling motion, and flagella are observed with the van Ermengem stain. No capsules have been demonstrated. Spores are frequently found central or subterminal in type and oval in shape. We have not found spores, as a rule, in fresh wounds, or in culture-media lacking carbohydrates. In media containing meat or rich in other proteins they are abundant. Many atypical forms of the bacilli may be encountered, such as oval, bulb, barrel (clostridial), or club-shaped forms. Miss Robertson,[3] of the Lister Institute, has described "citron" forms in smears taken from wounds. These are of varying length, of pale granular appearance, taking the stain irregularly. She considers these to be stages in a type of spore formation, and asserts that "they are specific to the Vibrion septique type among the pathogenic anaërobes at present known. When the citrons and oval or bulb types are found they afford an immediate and valuable diagnosis, but a failure to find these types does not constitute evidence that the case is free from an active infection with Vibrion septique." I found the oval types in smears, but did not observe the citron forms. Some writers have called the Vibrion septique a Gram-negative bacillus. Most writers describe it as Gram-positive.

In glucose broth there is rapid growth, with turbidity and gas production, with an odor of butyric acid. In about forty-eight hours there is a certain amount of deposit in the bottom of the tube. In broth containing a cube of white of egg no proteolytic action is found on the egg. In Veillon's agar there may be a slight production of gas. The colonies are characteristically arborescent, arising from a rather light central point, but we have seen cultures showing lenticular or heart-shaped nuclei giving off tufts of arborescent filaments. Litmus milk is acidified in twenty-four hours with a small amount of gas production. Coagulation may occur in from three to seven days or longer. Proteolysis is not shown either in the cube of white of egg or the milk.

Cross-agglutination tests should always be made to differentiate from other motile anaërobic bacilli, particularly the B. sporogenes.

Bacillus Sporogenes.—It is difficult to say which is the more common bacillus, as I found them in our cases, the Vibrion septique or the B.

sporogenes. For much of the time I was without one or the other specific agglutinating serum, or both, but, from the morphologic and cultural characteristics, I should say that in our cases the B. sporogenes was much the more frequent. It is believed by many observers that certain strains which have been described as Vibrion septique were, in reality, the B. sporogenes. Morphologically they are very similar. As seen in the stained smear it is impossible to distinguish between the two, unless it is by the presence of the citrons of the Vibrion septique, as described by Miss Robertson. The B. sporogenes is said to be more motile than the Vibrion septique, but motility is so variable, depending upon so many conditions, that we should not count upon this feature.

In glucose broth there is an abundant growth with much turbidity, and some production of gas in twenty-four hours. The odor is rather foul. In broth with a cube of white of egg there is proteolysis of the egg in twenty-four to forty-eight hours or longer. In Veillon's agar there may be some gas formation. The colonies vary greatly in appearance. They may appear as woolly balls or as regular or irregular lenticular nuclei, from which are given off arborescent filaments. A mass of dark, closely packed filaments may obscure part of the lenticular nucleus, giving the so-called "grenade" form. Litmus milk is acidified with some production of gas. The milk may be digested without coagulation, or it may be coagulated in small granules, which are later digested. The proteolytic property of the B. sporogenes aids in differentiating it from the Vibrion septique. Cross-agglutinating tests show that it reacts specifically to the anti-B. sporogenes agglutinating serum.

Bacillus Tertius.—This bacillus was found by Captain Herbert Henry,[4] R. A. M. C., so frequently that he gave it the name of B. tertius, the two bacilli found by him more frequently being the B. welchii and the B. sporogenes. I found it in very few of our cases. It is a Gram-positive bacillus with round terminal spores, and with slight or no motility.

In glucose broth there is turbidity, with some gas formation. In broth with a cube of white of egg no proteolysis of the egg is observed. There is a slight amount of gas production in Veillon's agar. The colonies are not distinctive, being of the lenticular or heart-shaped variety, with filaments given off at times. In our cases the litmus milk was acidified, but no further change was noted in ten days.

Bacillus Fallax.—I found the B. fallax present in a large number of our wounds. It is a Gram-positive bacillus, slightly longer and narrower than the B. welchii, with no spore formation. Motility is present, being more marked in the exudates than it is in cultures.

In glucose broth there is a vigorous growth with some gas formation, and an acid odor. White of egg in broth shows no proteolytic action. There is much gas formation in Veillon's agar, with about the same degre of fragmentation as with the B. welchii. The colonies are very similar to those of the B. welchii, but are perhaps slightly less opaque (Weinberg).

I had no agglutinating serum for the B. fallax, but it is reported that such sera are not always specific. It may be differentiated from B. welchii by its smaller size, motility, and the presence of flagella.

Bacillus Putrificus.—This bacillus was definitely diagnosed by us only once. It is a Gram-positive rod of about the same dimensions as the Vibrion septique, actively motile. It is a spore bearer, and the spores are always terminal.

It grows well in broth, and has a strong proteolytic action on white of egg. A strong putrid odor is given off. In Veillon's agar there is some gas formation. The colonies are small dark masses, like woolly balls, similar to, though smaller than, the colonies of B. sporogenes. Litmus milk is not acidified, but is digested without coagulation.

No specific agglutinating serum has yet been prepared for the B. putrificus, but it does not agglutinate with antisporogenes agglutinating serum. It may be differentiated from B. sporogenes by its terminal spores, and by its failure to agglutinate with the antisporogenes serum.

Bacillus Bifermentans.—This Gram-positive bacillus was found in our cases twice. In several respects it is similar to the B. welchii. It has the same form and dimensions as the B. welchii, and is not motile. It produces central spores rapidly in the media, however.

It grows well in glucose broth, and a cube of white of egg in broth is rapidly proteolyzed. In Veillon's agar there is gas production, and at first the colonies are lenticular, similar to those of B. welchii. After two or three days, however, there are masses of budding lenticular colonies, which are quite distinctive.

After four or five days' incubation litmus milk shows a precipitate of casein in fine granules which are rapidly digested. The fluid is of a dirty yellow color. The milk is not acidified. There is a strong putrid odor of sulphuretted hydrogen given off.

The B. bifermentans can be distinguished from the B. welchii by its formation of spores and strong proteolytic property, and from the B. sporogenes by its lack of motility. Furthermore, it is not agglutinated by the antisporogenes agglutinating serum. Weinberg suggests that when a culture of B. welchii is found containing a large number of spores, the presence of the B. bifermentans should be suspected and sought for.

In addition to the bacilli described above, which I found in our cases, there are two others which I examined in pure cultures given me by Dr. Weinberg. They are the B. œdematiens and the B. histolyticus, both described by Weinberg and Séguin. The B. bellonensis (described by Sacquépée[5]) shows certain characteristics similar to, if not identical with, the B. œdematiens. It is necessary to give a brief description of these bacilli, as they are pathogenic, and it is very probable that some of them at least were present in our cases and were overlooked. They are all strict anaërobes. Weinberg insists on the necessity of using broth freshly made and regenerated by boiling for fifteen minutes, incubating in tubes, and then exhausting the air from the tubes. I have succeeded in one instance in getting a very poor growth in broth of the

B. œdematiens, using the calcium sulphid and liquid petrolatum method. Subcultures in large amounts from this into Veillon's agar gave characteristic colonies. Agglutinating tests are not sufficiently diagnostic, as so many strains are auto-agglutinating, and animals are necessary for using antitoxic sera.

Bacillus Œdematiens.—This bacillus occurs as a Gram-positive rod as thick as the B. welchii, but longer. The ends are usually rounded, and the bacillus in cultures is generally curved. In the exudate from wounds it is most often straight, but sometimes slightly curved, usually in pairs, or more rarely in chains of four or five (W. and S.). Motility is slight, and is demonstrable under anaërobic conditions in fine capillary tubes under the microscope. Large, oval spores are rapidly formed, and are always subterminal. Many free spores are found in the broth. The Gram stain is positive in early cultures, but after twenty-four hours many bacilli are found to be Gram-negative. In old cultures very few Gram-positive bacilli are found.

In glucose broth there is turbidity, with auto-agglutination of the bacilli, and a thick deposit in the bottom of the tube. After forty-eight hours there is clearing of the medium, owing to the rapid degeneration of the bacilli. There is a slight formation of gas and a strong fetid odor. In broth with white of egg no proteolysis is observed.

In Veillon's agar there is a slight production of gas. Young colonies have an irregular, yellowish, opaque center, surrounded by a fine crown of short arborescent filaments. After a time the colony becomes paler and the center becomes vesicular. Many "grenade" forms are seen. At times it is impossible to differentiate the colonies from other arborescent types, such as the Vibrion septique and the B. sporogenes. Litmus milk turns acid in twenty-four hours, with some gas formation. Coagulation was not observed, up to two weeks in the incubator, in the strains which I examined.

Agglutination tests are of no value, as most strains are auto-agglutinating. The only sure methods of differentiating this organism are by animal inoculations for pathogenicity, and the use of specific antitoxic serum.

Bacillus Histolyticus.—This is a Gram-positive bacillus of practically the same form and dimensions as the B. sporogenes and the Vibrion septique. In exudates and in twenty-four-hour broth cultures it appears always as a diplobacillus, with a clear space between, and rounded ends. Motility is present in young cultures and is similar to the rolling movement of the Vibrion septique. Many flagella (twenty or more) are seen on staining. Large oval subterminal spores are readily formed in all media. Young bacilli are Gram-positive, but in old cultures are found quill forms, granular, and fusiform bacilli, which take the stain poorly.

In glucose broth there is turbidity in twenty-four hours, with a deposit in the bottom of the tube, clearing in a few days. No gas is produced. There is a slight specific fetid odor. In broth with white of egg, the white of egg is slowly rendered transparent, and almost

completely digested. In Veillon's agar young colonies have somewhat the appearance of colonies of B. sporogenes of the same age. Older colonies resemble those of B. œdematiens. There is no gas formation. Litmus milk is slowly acidified. It coagulates in fine granules which are completely digested. In eight to ten days it is transformed into a clear, yellowish liquid, with a very slight odor.

As many strains of B. histolyticus are auto-agglutinating, the use of agglutinating sera cannot be depended upon for a correct identification. An antitoxic serum, however, affords a means of identification by neutralizing the toxin and the corresponding cultures.

The antitoxic serum of Vibrion septique does not neutralize toxins of B. histolyticus, and vice versa. The B. histolyticus does not agglutinate with the antisporogenes agglutinating serum.

The differences between the B. œdematiens of Weinberg and Séguin[6] and the B. bellonensis of Sacquépée appear to be very slight so far as their morphologic and cultural characteristics are concerned. Certain strains of each appear to be very nearly identical. It has been shown that colonies of the same strain may vary very greatly in appearance, so that this feature should not be insisted upon as a differential point.

The B. tetani was not found in any of our cases.

PATHOGENICITY

Many of the anaërobic bacilli appear to be pathogenic in themselves, while others seem to be pathogenic only in symbiosis, either with other anaërobes or some of the aërobes. It has been demonstrated that B. welchii, the Vibrion septique, B. œdematiens, and the B. histolyticus are pathogenic in themselves, while most of the other anaërobic bacilli appear to play what may be termed preparatory rôles.

The bacilli which seem to be most prominent in the causation of gas bacillus infection are the B. welchii, the Vibrion septique, and the B. œdematiens (B. bellonensis?). They may be present alone in the lesions, or may be seen in various combinations with the other pathogenic or non-pathogenic anaërobic bacilli. Some of these latter appear to aid in the process by producing putrid conditions, or gas, or both, in the wounds.

We have seen that in the first six or eight hours bacteria are not usually found in any considerable number, microscopically, in smears taken from wounds. Cultures made at the same time usually show only a few colonies. The first bacteria to appear are usually cocci, either singly or in pairs, followed by the presence of Gram-positive bacilli, of which the B. welchii seems to be the most rapidly growing. At the end of twenty-four hours the growth of both aërobes and anaërobes is well established in the great majority of untreated wounds. From the fourth to the tenth day the anaërobic bacilli diminish in growth and in virulence. During this time the cocci also show less growth, some of them tending to disappear, while the more virulent forms, such as the hemolyzing cocci, persist. During this period we frequently note the appearance of other bacteria, such as the B. coli, B.

proteus, and the B. pyocyaneus. Also during this period we may have the development of certain anaërobic bacilli, such as the B. sporogenes, causing putrefactive changes in the wound.

In a wound treated either by operation (débridement and excision) or by Carrel's method we see quite a different picture. After operation, if properly performed, cultures show rare colonies, usually of cocci, single or in pairs. Owing to the removal of devitalized tissues, which offer the most favorable factor for their growth, we find few, if any, anaërobic bacilli. In such an event, if the cocci are not of the hemolytic type, they usually disappear at an early date, and the case is usually ready for an early closure.

A certain number of cases are too severely wounded for a radical débridement and excision of tissues. In such a case the surgeon removes as much of the devitalized tissues as possible, and institutes the Carrel system of drainage and irrigation. Here we may have enough of a focus of devitalized tissue and bacteria left behind to allow of the development of a certain number of both aërobic and anaërobic bacteria. Owing to the access of oxygen and the elimination of toxins, and the products of putrefaction, we usually have a rapid diminution, both in number and virulence, of the bacteria. A certain number of cases, however, under such conditions will show a development of anaërobic bacilli leading to gas gangrene.

Aside from the question of gas gangrene the most important complication we have to deal with is infection with hemolytic cocci. This is important in any case, but especially so when there is infection of bone tissue. It is practically an axion that every case of sinus leading down to a bone, in a wound of long standing, is infected with hemolytic cocci, usually streptococci. In such an event we should always advise against closure of the wound until several repeated cultures show the absence of hemolytic cocci.

GAS GANGRENE

The subject of gas gangrene is too extended to allow of more than a short résumé in the present article.

No case of gas gangrene caused by aërobic bacteria was discovered in our hospital. All cases of gas gangrene are caused by anaërobic bacilli, singly, in combination with other anaërobic bacilli, or with aërobic bacteria. The majority of cases of gas gangrene are caused by the action of two or more anaërobic bacilli. The cases seen at our hospital were caused more frequently by the B. welchii than by any others. The bacillus most frequently found by us in combination with the B. welchii was the B. sporogenes. In several cases the determining organism, either alone, or in combination with others, was the Vibrion septique. We did not demonstrate the presence of the B. œdematiens in any of our cases. Among the aërobes found in cases of gas gangrene, the most frequent were non-hemolytic cocci, usually of the Diplococcus griseus type. Enterococci were also frequently found. We frequently found also the B. proteus, members of the B. subtilis group, and the B.

mesentericus. Hemolytic streptococci or staphylococci were found in a comparatively small number of fresh wounds. The presence of anaërobic bacilli in blood-cultures was not demonstrated in any of our cases.

For the clinical classification of the different forms of gas gangrene, that of Weinberg and Séguin[7] seems to me the most logical. They classify them into the following groups:

1. The classical type. 2. The toxic type. 3. Mixed types.

All of these three may be complicated with the putrid varieties.

1. **The Classical Type.**—In this form of gas gangrene there are two principal infecting organisms, the B. welchii and the Vibrion septique. The cardinal symptoms of this form are: (1) the production of bubbles of gas in the tissues; (2) sometimes, but not always, crepitation in the overlying tissues; (3) bronzing of the skin; (4) occasionally the formation of bullæ in the adjacent skin; (5) loss of contractility and change of color in the muscle-fibers, and (6) in fatal cases, septicemia. Among our cases, not all the foregoing symptoms were present in any one case. There may be any combination of these symptoms present, depending upon the location and the severity of the wound. In addition to the above-mentioned symptoms there may be present an odor of butyric acid, or a putrid odor. When there is a large amount of gas in the tissues the infecting organism is usually the B. welchii. In cases where the Vibrion septique has been found to be the principal infecting organism, there is usually to be found less gas production than where the B. welchii is the cause. The most important single symptom is the loss of contractility, and the change in color of the muscle-fibers. In the great majority of cases of this type of gas gangrene the B. welchii has been demonstrated to be the causal factor.

2. **The Toxic Type.**—In these cases the predominating features are general symptoms of intoxication and a progressively invading edema of the tissues, which may mask the production of gas in the tissues. Septicemia is rare. The muscles show hyperemia and are edematous. The intercellular tissue presents a gelatinous white edema. There is no putrid odor. Weinberg and Séguin[8] consider that these cases are usually caused by the B. œdematiens, but they cite one case where, in addition to the white edema, there was some gas in the wound, and crepitation near the wound. Cultures showed the presence of the B. welchii alone, of the anaërobic bacilli. One case of this type was found in the hospital, but without gas and crepitation.

3. **Mixed Types.**—The B. welchii, or the Vibrion septique, may be present in a wound in combination with the B. œdematiens. In such a case one might observe the existence, at the same time, of an extensive gaseous crepitation and a marked white edema. Such cases have been reported, but we did not observe them at our hospital.

Several putrid varieties of gas gangrene have been observed. I found one case in which the B. sporogenes was the only anaërobic bacillus present. It may be, and usually is, present in combination with the B. welchii, the Vibrion septique, or the B. œdematiens. It is

by far the most common organism producing putrid conditions in wounds, but I also found present the B. bifermentans and the B. putrificus contributing to similar conditions.

The question naturally arises, Why, when practically all wounds are infected with anaërobic bacilli, does gas gangrene occur in some untreated cases and not in others? The reason must be sought in the consideration of two main factors, mechanical and bacteriologic.

It is easily understood that, in addition to the foregin bodies carried into a wound, one must take into consideration not only the traumatism of soft parts, but also that of bones, vessels, and nerves. We have seen that spicules of bone may be scattered widely throughout the neighboring tissues, and may carry with them numbers of bacteria, particularly the anaërobes. If these spicules of bone are not thoroughly removed we have present a very good focus of infection in devitalized tissue, without which anaërobic bacilli do not tend to develop. Also, a projectile fracturing a bone may carry into the medulla enough bacteria to give rise to an infection, and, in such an event, local treatment is almost powerless to prevent the development of severe infection.

Wounds involving the larger arteries and veins are extremely important, inasmuch as the local blood-supply of the affected part is diminished, adding to the already devitalized condition of the soft parts, and bringing less oxygen to the tissues. Dressings and splints applied too tightly may also cause a similar condition. Wounds involving nerves, so far as they affect the nutrition of the tissues, may also aid in the further devitalization of the tissues, favoring infection. Consideration of these factors will partially explain why, in a certain number of cases, the development of gas gangrene is delayed in its onset.

In the consideration of the bacteriologic factors leading to the production of gas gangrene we encounter several elements. One of the most important of these is the association, or symbiosis, of bacteria, both aërobic and anaërobic. It is a debatable point as to how far the presence of aërobes in a wound tends to increase the virulence of anaërobic bacilli. Researches of various workers in this field lead to quite different conclusions. It is generally admitted, however, that the presence of aërobic bacteria tends to favor the growth of the anaërobes by depriving the affected tissues of their oxygen. It is also not improbable that the products of metabolism formed by the aërobes, and their action on the tissues, may be a favoring element. When two or more types of anaërobic bacilli are found in a wound, the action of one, such as the B. welchii or the Vibrion septique, may be increased by the putrefying effect of such an anaërobe as the B. sporogenes, or the histolyzing effect of the B. histolyticus.

Anaërobic bacilli do not grow readily in healthy living tissue, but in war wounds we find ideal conditions for their development. Here we have already devitalized tissue and a nidus of bacteria which will produce the conditions under which the anaërobic bacilli will grow most favorably, if the wound be left untreated. If the wound is operated upon at an early hour, and a complete débridement and excision of all

the devitalized tissues and foreign bodies be made, a process of gas bacillus infection may be prevented. If it has already begun, it may be arrested by supplying oxygen in the form of air to the wound, and the constant elimination by irrigation, as in Carrel's method, of dead tissues and the products of putrefaction.

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CHAPTER XV

SURGICAL TECHNIC*

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Remarkable and unexpected as it may be, certainly surgery has made a notable advance during the progress of the late Great War and, it may be added, as a result of it. With possibly the exception of the abdomen and of the head, advancement has been made in all fields of surgery, but it is most apparent in the department of technic, both aseptic and antiseptic. It is still more remarkable that this improvement in technic was started and continued in the advanced military hospitals, that is, the hospitals where the wounded were first stopped for treatment, the Casualty Clearing Stations of the British, the Hôpiteaux Evacuations of the French, and our own Mobile and Evacuation hospitals. These were all placed as near the fighting line as was deemed safe and, with the exception of a comparatively small proportion of the wounded so badly shocked or so depleted from loss of blood that transportation was deemed very dangerous, all primary operations were performed in them. At times of great activity the base hospitals nearest the front acted as evacuation hospitals and thousands of primary operations were done in them. It was in these advanced hospitals that military surgery was revolutionized and such strides made in aseptic technic that its effect has already been felt in civil practice and the surgery of peace enormously benefited.

There are those who will deny or doubt the benefit of this work to civil surgery, but they are those who have not seen hundreds of dirty shell wounds with extensive destruction of tissue and containing bacteria capable of producing a fatal infection in a few days, excised and successfully closed at once; who have not seen scores of extensive wounds of the knee-joint, which formerly required resection or amputation, treated in the same way; who have not seen great infected wounds of the buttocks and thighs, often complicated by comminuted fracture, sterilized and closed by secondary suture; and who have not seen old empyemas in which the proper employment of the Carrel-Dakin treatment has resulted in the sterilization of the cavity and its subsequent closure, a thing unthought of before the war.

Before this war we all pictured to ourselves military surgery on the field as a haphazard, go-as-you-can type of surgery, accompanied by an enormous mortality and always followed by infection. Although to some extent this is true in a great battle, where the hospitals become

* Supplementary to Chapter LXXII, Vol. V, p. 587, and Chapter CXLIII, Vol. VI, p. 891.

congested and the personnel and transportation is not large enough to handle the wounded properly, it is not true during four-fifths of the time. The only doubters for whom one can have any sympathy or any comprehension are those who were so situated in this great strife as to come in contact with the wounded before they reached the advanced operating centers or who only saw the surgery in these centers during the progress of a great battle.

It was, however, a common observation that the surgeons who had developed the perfected technic of wound treatment turned out much better results, even in times of rush, than those who deemed the practice of this technic unnecessary in military surgery.

In view of what has been said it will be understood that what follows in this chapter on technic is not a re-editing of what appeared in the earlier chapters of this work on the subject, but is practically a *rewriting* of them, and that it must consist largely of a description of the treatment of war wounds, leaving the reader to make his own application of it to civil surgery. This application will, of course, be made largely in the field of the wound infections, but much that is said on the treatment of war wounds applies to the accidental wounds of civil life, although it is granted that these do not represent the same extensive destruction and contamination of tissue.

The Technic of Primary Treatment of Accidental Wounds.—At the time of publishing the last supplementary volume of this work the treatment of gunshot and other contaminated wounds might have been summarized as consisting in the removal of the foreign bodies, the excision of tissue that was known to be dead or deprived of its circulation, irrigation with an antiseptic solution, and the partial closure of the wound with adequate drainage. In the first period of the present war the same plan was generally followed, but owing to the work of men like Lemaitre, Gray, Depage, Leriche, and Duval this was soon shown to be insufficient, and that with another type of treatment these wounds could be practically sterilized without the use of any germicidal agent and closed by primary or retarded primary (within a week) suture. The remarkable thing about this new method was its application to wounds of joints and of the chest. Before the war a surgeon daring to close at once with no drainage a gunshot wound of the knee-joint or chest would have been subject to a suit for malpractice, and yet during the last year or two of the war one who did not so treat these wounds was considered a very poor surgeon. In the American service, following the experience of our Allies, there was a definite rule that all wounds of the chest and large joints must be completely closed after proper débridement, if the operation was done in a reasonable time after the receipt of the wound.

In this connection it is important to say a word regarding the time at which the operation should be done in the case of contaminated wounds. A distinct line should be drawn between contamination and infection; practically every accidental wound is contaminated with bacteria, but infection of the tissues only occurs after the lapse of a

number of hours, varying from six to eighteen, according to the organism which is present and the amount of damage to the tissues, which lowers their resistance to infection. It must then be apparent that the sooner the treatment is instituted, the greater likelihood there is of successful closure of the wound, and that, after infection has occurred, the greater the difficulty in the sterilization of the wound. It was the appreciation of these facts that brought about the great change in military surgery and the placing of the operators and the operating centers as near the fighting line as comparative safety would permit.

Nothing should be done to a wound except to protect it from further infection by sterile dressings until one is prepared to do everything that may be required and in an absolutely aseptic manner. The one exception to this statement is the occurrence of *active hemorrhage.* This, of course, must be controlled, preferably by ligature. In most wounds caused by missiles hemorrhage is only temporary, and any extensive exploration of the wound is apt to start it up again; therefore, unless it is apparent that active bleeding is taking place, it is better to move the patient to a place where the complete primary treatment of the wound can be aseptically carried out. I have seen numerous instances of complete division of large vessels, like the femoral, popliteal, brachial, and tibials, by shell fragments, without bleeding until the clot in the vessel was disturbed. The tourniquet proved to be a dangerous and uncertain means of controlling hemorrhage in many instances in war surgery, as it has in not a few cases in civil practice. It is often too loosely or too tightly applied, it may slip in the course of transporting a patient, causing a fatal hemorrhage, and its prolonged application will result in lowered tissue resistance to infection, and may result in gangrene requiring amputation. I have known more than one patient to lose his life in an ambulance from the too loose application of the tourniquet or from its slipping, and in many cases where its prolonged use necessitated an amputation which otherwise would not have been required. For these reasons hemorrhage was controlled by ligature at the first available place, and no patients were allowed to be transported over long distances with a tourniquet still in place.

After the battle of St. Mihiel there was found in the captured property of the Germans a tourniquet which Truesdale[1] has modified as shown in Figs. 95–97. The surgeons of Mobile Hospital No. 39, of which Truesdale was one, found that the German tourniquet was very useful. His modification of the tourniquet, which enables one easily to regulate the pressure which it exerts, greatly improves it, and it certainly offers many advantages over the old methods of constriction.

It is necessary also to warn against the use of the probe or the finger to determine the presence of a foreign body or the possible penetration of the abdomen, chest, or joints. This determination must be made at the time the wound is being operated upon and not before to satisfy the curiosity or the desire to "properly classify" by the investigator. The probe, in fact, has no place in the paraphernalia of the modern military surgeon, as it is misleading and dangerous.

The time, then, to institute the treatment of the wound is as soon after its receipt as possible, in a place offering every facility, and the treatment should be in the hands of one who has developed the proper aseptic technic. Profound shock may be a legitimate cause for delay, but it must be remembered that as soon as the patient's condition will permit the operation must be done, for delay means certain infection of the wound.

In one of the French Evacuation Hospitals I saw the results obtained in the treatment of extensive wounds, especially of the head, chest, and abdomen, by a method which the author, Jean Bouchon, termed

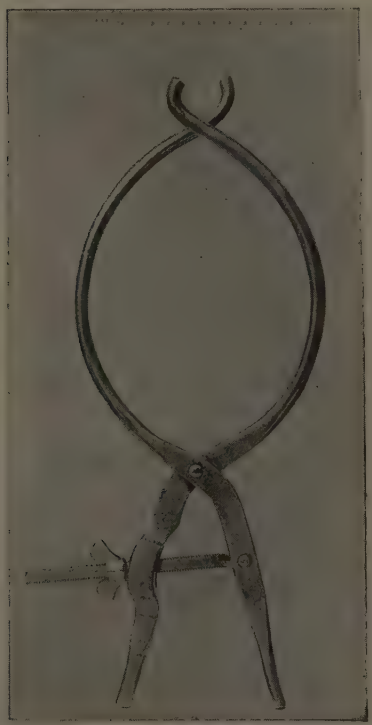

FIG. 95.—TRUESDALE'S MODIFICATION OF A GERMAN TOURNIQUET.

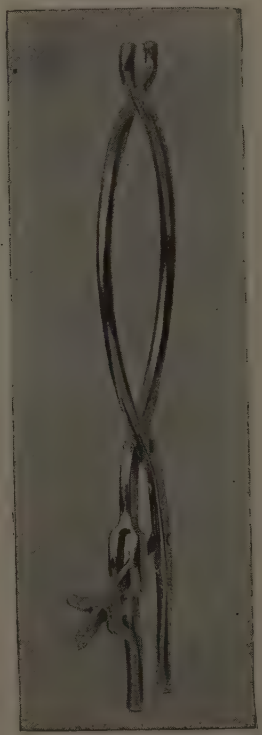

FIG. 96.—TRUESDALE'S MODIFICATION OF A GERMAN TOURNIQUET. SIDE VIEW.

"Fixo-décapage." The primary object of the treatment was to fix or destroy the organisms which would later produce infection by the application of a strong formalin solution applied on gauze packing. Later the separation of the resulting eschar was hastened by the daily use of Labarraque's solution. Bouchon used this treatment in nearly all wounds, which seemed to me to be a mistake, but I thought if its application were confined to large wounds and the cases of multiple wounds where the ideal operative treatment could not be carried out because of the shock, the method might prove of great advantage. I saw a number of badly wounded men in his wards making good re-

coveries, who at the time the treatment was instituted could not have withstood operation and who probably would have developed serious infection of the wound during the time necessary to treat the shock successfully. The author had used the method extensively in the advanced dressing stations for severe wounds of the head, chest, and abdomen. The wounds of entrance were simply enlarged and every part of the wound packed with gauze saturated in the formalin solution. This agent not only interferes with the activity of the organisms but also has the advantage of being hemostatic. The packing is not removed for a number of days, and then only gradually. The solution produces a deep eschar all over the surface of the wound, and a separation of this is later hastened by the use of Labarraque's solution.

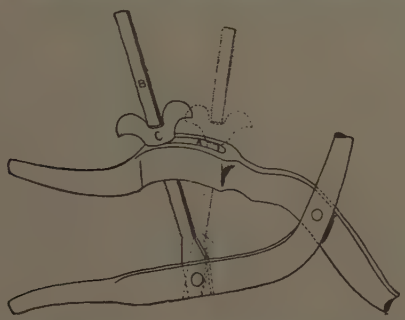

FIG. 97.—HANDLES OF TRUESDALE'S MODIFICATION OF A GERMAN TOURNIQUET.

A, Slot through which adjustment screw *B* passes; heavy lines represent adjustment screw holding clamp in position of compression with thumb-nut *C* set; broken lines represent adjustment screw shifted and compression released.

I have not been able to find any reference in the literature to this method, but Bouchon published privately a description of it. The formula of the solution is as follows:

Strong fixing solution	Formalin, 40 per cent.,	30 c.c.
	Alcohol,	500 "
	Ether,	500 "
	Methylene-blue,	3 gm.
Weak fixing solution	Formalin, 40 per cent.,	20 "
	Sodium chlorid,	50 "
	Sodium borat.,	50 "
	Boiling water,	1 liter
	Methylene-blue,	3 gm.

The weaker solution is used in wounds which have already become infected, especially with anaërobic organisms, as the "fixing" quality of the weaker solution lasts much longer.

Preparation of Field of Operation.—In Volume VI stress was laid on the danger of infection from the use of "scrubbing brush and soap," and here again it might be emphasized. Iodin or picric acid are perfectly satisfactory agents for the sterilization of the skin, and in their use one is sure that he is not carrying a new contamination from the skin into the wound. Ether, alcohol, or benzene may be used also, but we prefer to follow them with iodin or picric acid. The preparation

of the skin should extend over a much wider area in the case of gunshot wounds than in preparation for an operation of known extent, for in operating on gunshot wounds the operator often finds himself led far beyond the area he at first supposed to be involved.

Gibson,[2] of New York, states that in 1917, when with the British Army, he became familiar with the use of picric acid in 5 per cent. alcoholic solution, as a substitute for the tincture of iodin in the disinfection of the skin. He was very much impressed with its efficacy, and has since used it in a number of cases at the New York Hospital with excellent results. No irritation of the skin follows its use, but the skin, after being painted, should be allowed to become perfectly dry before the operation is begun.

Mitchell[3] reports from the Pathological Laboratory of the University of Missouri the reliable germicidal qualities of picric acid in 1 per cent. alcoholic solution. Apparently these results have been confirmed by clinical experience as reported in his communication.

Débridement.—This term has become so universally employed to represent the technic of mechanical sterilization of gunshot wounds that it is fair to presume that it will keep its place in the English language. Although it literally means "unbridling or liberation," it practically indicates in surgery the freeing of the wound of all foreign material and of all devitalized and contaminated tissue. The English term "excision" is used to express the same thing, but it would seem better, I think, in order to avoid confusion to appropriate for all time the term débridement, which is now universally used and generally understood. Like most advances in surgery, débridement of gunshot wounds is not the product of one mind, and it would seem that in this case credit must be divided largely between Gray, of the British Army, Depage, of the Belgian Army, and Lemaitre, of the French Army. Gray,[4] in August, 1915, described débridement or excision very carefully and urged its employment with primary suture in many of the wounds. He says that he first began this method in November, 1914, in the case of superficial gutter wounds.

The idea of mechanical disinfection is not altogether a new one. Tinker[5] in a communication recommended it in the treatment of lacerated and contused wounds, and also that it be followed in certain cases by primary suture; but its general application to wounds of war is new and represents one of the greatest advances made in traumatic surgery in many years.

Depage and Lemaitre did much by their writings and demonstrations to convince the surgeons of the Allied Armies of the great importance of débridement, and the American surgeons must always be grateful to them.

Depage presented a paper in Paris before a meeting of the American surgeons in which the method of débridement and primary suture was carefully described. He showed that débridement was not a rough, haphazard excision of the wound, but a careful, painstaking, and delicate removal by the knife of all contaminated and devitalized tissue,

with, of course, the removal of all foreign bodies. A number of mistakes were made in the early practice of débridement because the devitalized muscular tissue was not recognized and removed. The de-

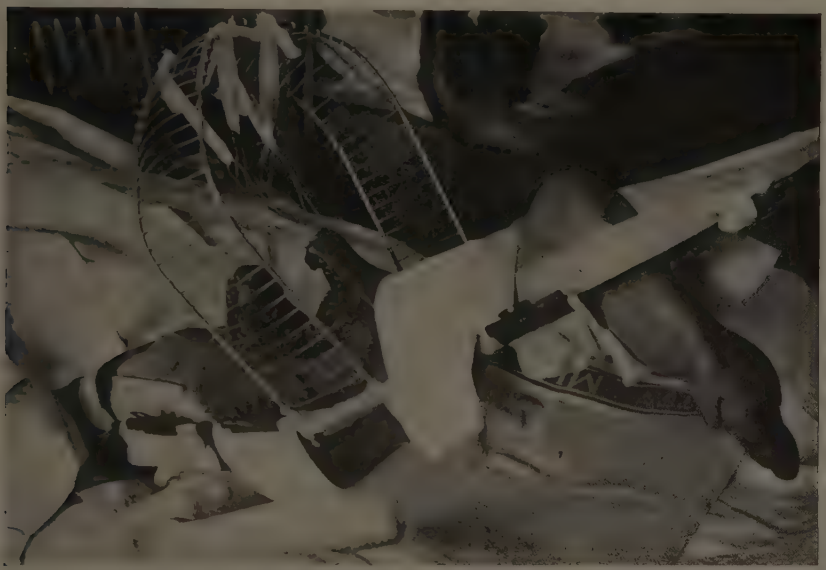

Fig. 98.—Large Perforating Shell Wound of Calf with Complete Division of Gastrocnemius Muscle. Skin and Muscle Flaps Held Up by Silver Wires to Frame to Prevent Contraction. Later Closed by Secondary Suture. (Heuer.)

vitalized muscle can be recognized by the fact that it has lost its pink color, that it does not contract when pinched or cut, and that it does not bleed when cut. Many failures occurred because a complete débridement had not been done. Unless the operator is absolutely sure that

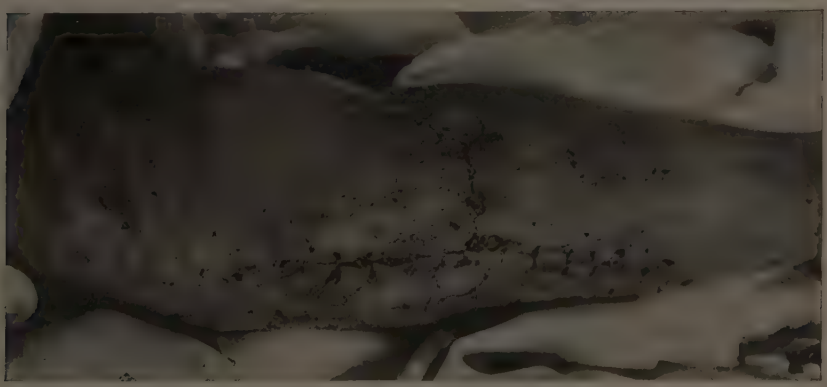

Fig. 99.—End-result of Secondary Suture of Skin and Muscle Flaps. (Heuer.)
Same case as shown in Fig. 98 with flaps held to frame.

he has removed all contaminated and devitalized tissue, no attempt should be made to close the wound, but it should be left wide open, sterilized by the Carrel-Dakin method, and closed by secondary suture.

Depage emphasized the fact that the failures from primary closure were accompanied by very severe systemic infections, which were often fatal, especially if due to the gas bacillus, and that the failures from retarded

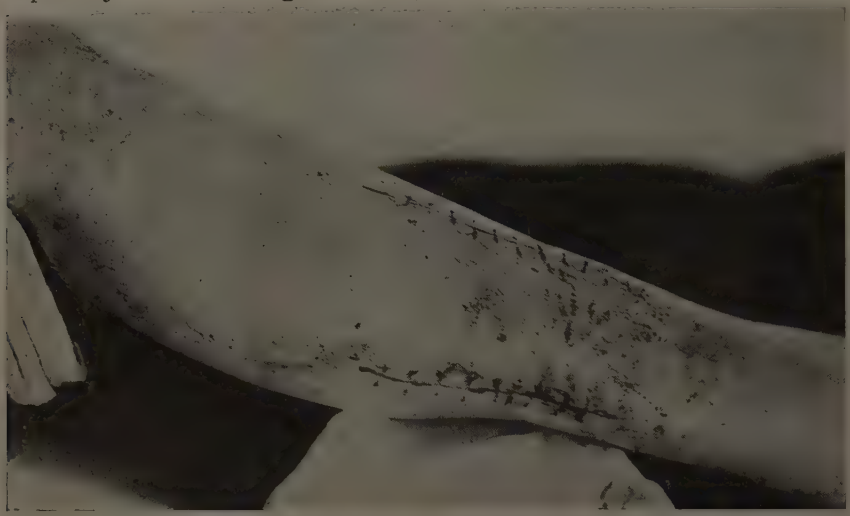

FIG. 100.—LARGE PERFORATING SHELL WOUND, OUTER ASPECT, LOWER LEG. CLOSED BY RETARDED PRIMARY SUTURE. (Heuer.)

primary (within seven days) or secondary suture were rarely accompanied by any such risk. My own feeling is that a surgeon should first perfect himself in débridement before attempting primary suture. When he finds that he is able to close his wounds in a day or two after

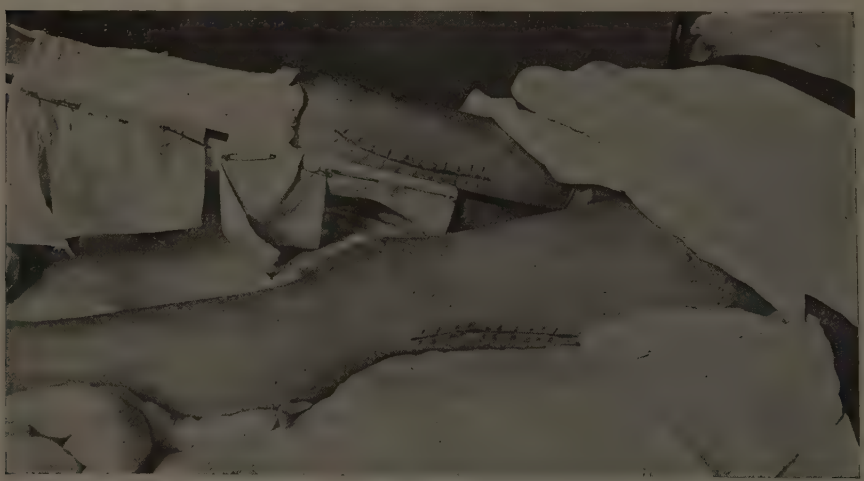

FIG. 101.—PERFORATING SHELL WOUND, LEFT THIGH, THE SAME MISSLE PENETRATING RIGHT THIGH AND FRACTURING RIGHT FEMUR. SHELL WOUND CLOSED BY PRIMARY SUTURE. (Heuer.)

débridement, he can then begin the immediate primary closure. It should be understood that the small and superficial wounds, especially those about the face, neck, hands, and feet, can be more readily closed

by primary suture than the large wounds about the trunk, buttocks, thigh, and calf, and particularly those accompanied by comminution of bone. The Depage technic was adopted immediately on the establishment of the first American Evacuation Hospital, No. 1, in the Toul Sector, and it was with great satisfaction that I saw the results tabulated

FIG. 102.—SAME CASE AS PRECEDING, FIG. 101, SHOWING THE COMPOUND COMMINUTED FRACTURE OF THE RIGHT FEMUR SHATTERED BY THE SAME MISSILE AS WOUNDED THE LEFT THIGH. SUCCESSFULLY CLOSED BY PRIMARY SUTURE. (Heuer.)

in Depage's communication practically duplicated, after a little experience, by Poole, McWilliams, Heuer, Vaughan, and Jopson, who headed the surgical teams at this hospital. A number of photographs taken by Heuer illustrating primary, retarded primary, and secondary suture are here reproduced. It should be added that the results ob-

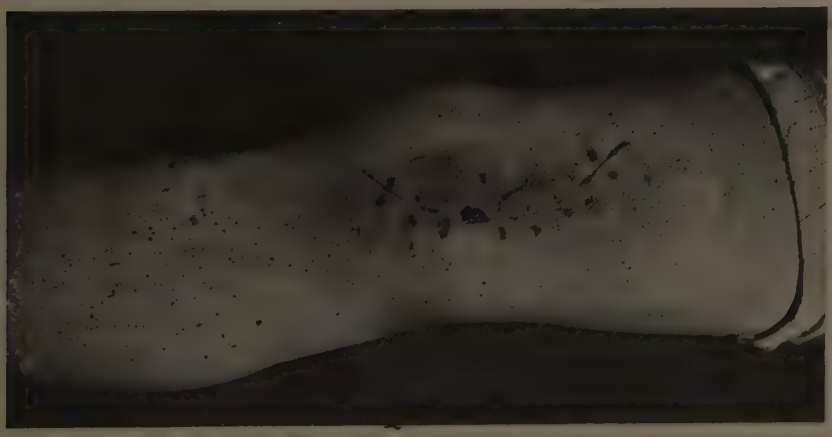

FIG. 103.—PENETRATING SHELL WOUND, INTERNAL ASPECT RIGHT KNEE, WITH COMPOUND COMMINUTED FRACTURE OF INTERNAL CONDYLE, FEMUR CLOSED BY PRIMARY SUTURE. (Heuer.)

tained in this hospital in secondary suture were entirely due to the fact that the surgeons carried out in every detail the Carrel technic. If such results can be obtained in an evacuation hospital in time of war from wounds badly infected, it must be apparent that the same results should be obtained from infected wounds in civil life. Later equally good

results were obtained by hundreds of surgeons in a number of American hospitals.

In a late paper read by Depage[6] before the American Surgical Association will be found a full discussion of this subject. This paper will prove as valuable to the civil surgeon as to the military surgeon, because the principles laid down are applicable to every-day surgery.

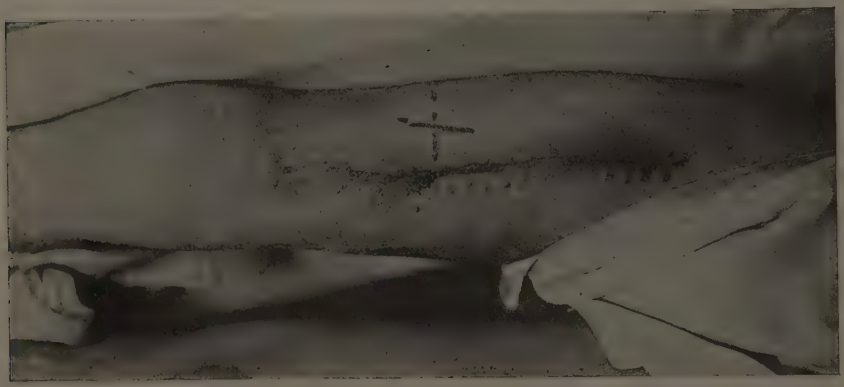

FIG. 104.—LARGE PERFORATING WOUND OF THIGH CLOSED BY SECONDARY SUTURE. (Heuer.)

One of the old customs in the treatment of contaminated and infected wounds most difficult to give up was the partial closure with the insertion of drains. Yet, if the new technic was to be adopted, this old custom must be dropped, and wounds either closed immediately and completely, or left wide open. It must be understood that the sterili-

FIG. 105.—LONG PERFORATING WOUND OF THIGH WITH OPENING OF KNEE-JOINT. CLOSED BY PRIMARY SUTURE. (Heuer.)

zation of a wound is much more readily accomplished, and its subsequent closure possible at a much earlier date, if the wound is wide open than if it be partially closed with drains. Another advantage in leaving the wound wide open, if it is not completely closed, is that serious systemic infection, if débridement has not been complete, is much less apt to occur.

Many French surgeons, particularly Lemaitre, reported excellent results in primary and retarded primary suture after careful débridement without the use of any disinfecting agent, and the only explanation of the results is that the primary débridement must have been perfect.

The Treatment of Infected Wounds.—This has been revolutionized by the introduction and establishment of the Carrel-Dakin treatment. Although this treatment represents the re-introduction of an old germicidal agent, hypochlorite of soda, this agent has been so altered by Dakin as to lose much of its irritating tendency and yet retain its germicidal quality. Another feature of the treatment is its application, upon which too much stress cannot be laid, as many false impressions in regard to the treatment have arisen from improper application.

In their endeavors to have this method adopted in the military hospitals of France in 1915 Carrel and Dakin met with a great deal of opposition, which, it should be said, was based on theory and not on study of the method or on observation of the results obtained by its proper employment. One visit to Carrel's hospital at Compiégne should have been enough to convince the greatest doubter of its efficacy. In visits to scores of other hospitals where this method was not used I never saw wounds that were in any way comparable to those in his wards. Depage, Tuffier, Chutro, and others, however, were obtaining the same results with the same treatment in their hospitals.

It should be said at once that Dakin's solution is not the same as Labarraque's solution, but a neutralized hypochlorite of soda, which, in consequence, loses the irritating quality due to the alkali in Labarraque's solution.

It is only fair to Carrel and Dakin that in the employment of Dakin's solution and the Carrel method of applying it one should adhere minutely to the authors' method of preparation and application. The following quotations in regard to this treatment are taken from "The Treatment of Infected Wounds," by Carrel and Dehelly (Hoeber, New York City, 1919): "This solution contains a mixture of hypochlorite and polyborate of soda and small quantities of free hypochlorous acid and boric acid. In this manner the irritating action of caustic soda is avoided. In fact, if alkali should form, it would be immediately neutralized by the boric acid and the acid borates present in the solution.

"Dakin's hypochlorite differs from eau de Javel and Labarraque's solution in that its destructive action upon the tissues is very slight. Study of the communications made to the learned Societies of Paris, and particularly to the Académie de Médicine, shows that the necessity for using a non-caustic antiseptic has not been grasped. Surgeons do not yet comprehend that Dakin's solution, containing no free alkali, can be employed under conditions where the use of eau de Javel or Labarraque's solution would be absolutely impossible."

The authors have demonstrated very plainly that the hypochlorite solution of Dakin destroys toxins as well as bacteria. Although the

solution is but very slightly toxic when used in wounds, it becomes actively so when introduced into the circulation. It has been often said that the employment of Dakin's solution in actively suppurating wounds tends to the production of secondary hemorrhage, and I have seen a number of such hemorrhages in the British service where we were using eusol, which was the common substitute for Dakin's solution. Carrel points out very carefully that the solution dissolves tissues which are deprived of circulation.

"Similarly, the clots which often obliterate vascular wounds are enabled to dissolve under the action of hypochlorite. For this reason we must carefully examine the condition of the vessels at the moment of surgical intervention, and must effect an accurate preventive hemostasis."

It must be said, however, that the secondary hemorrhages which I saw took place in the wounds which were actively suppurating and, in my opinion, the hemorrhage was due to suppuration and not to the solution.

Another objection which is cited is that cicatrization is delayed by the prolonged use of Dakin's solution. This has not been my own observation. In regard to this Carrel says: "In short, in the healing of an infected wound the acceleration produced by hypochlorite is due to its antiseptic power. Hypochlorite does not appear to have any marked action on the tissues in the direction of cicatrization when it is used under the conditions of our experiments. Probably it has a slightly retarding effect on the healing of aseptic wounds. But in practice this influence is negligible."

"Dakin's solution, therefore, we may conclude, when applied under suitable conditions does not harm in any appreciable manner tissues under repair, which is contrary to the belief of most surgeons."

Carrel also emphasizes the importance of the early treatment of wounds, which has already been referred to. In this connection he says: "The modifications of the bacteriologic aspect of a wound from the fifth or sixth hour to the twenty-fourth hour were due to the rapid division of micro-organisms. If it be supposed that each microbe divides every half-hour, it will give birth in twelve hours to more than 15,000,000 other microbes. This extreme rapidity of multiplication explains why wounds twenty-four hours old are already invaded by myriads of micro-organisms."

It is true, then, just as we should endeavor to perform débridement, or mechanical cleansing of a *contaminated* wound, as soon after its receipt as possible, so also the chemical sterilization of an *infected* wound is more quickly accomplished if it is begun early. It is not an easy matter to sterilize old suppurating wounds. The difficulty lies largely in the fact that the organisms are protected from contact with the antiseptic fluid by blood-clot, granulation tissue, and foreign material. "From the practical point of view, in the suppurating wounds of the soft parts, contact between microbes and antiseptic sufficient to assure surgical sterilization is possible of attainment. In deep wounds with

pus burrowing along muscular interstices, where contact between antiseptic and microbe cannot be realized, results are less favorable. When suppurating wounds are accompanied by fractures, or the osseous fissures described by Policard, along which the micro-organisms are propagated, it becomes impossible to make the liquid penetrate into all the infected places. Similarly, when osteomyelitis has declared itself, or when splinters have been left in the tissues, the conditions are the same. Microbes establish themselves in the sequestra at such a depth that the antiseptic cannot penetrate to them. They are protected by their situation at the same time against the chemical agent and against the polynuclear cells coming from the normal tissues. This is the reason why the infection is so extremely tenacious when bony lesions or necrosed splinters persist at the bottom of irregular wounds.

"This brief examination of the topography of infection shows that in the majority of cases it is possible to obtain intimate contact between antiseptic and microbe. Suitable preparation of the wound for the penetration of the germicidal substance, and distribution of this substance over the whole of the affected surface, will enable this contact to be realized. If, up to the present, we have not succeeded in chemically sterilizing wounds, it is, in part, because we have neglected to prepare them in such a manner that the antiseptic substance may reach every point where microbes exist."

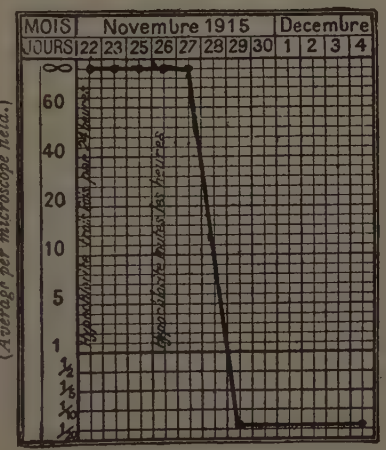

FIG. 106.—NECESSITY FOR PROLONGED CONTACT BETWEEN THE ANTISEPTIC AND THE WOUND. (Carrel and Dehelly.)

Highly infected atonic wound treated up to November 26th by application of hypochlorite three times a day. No diminution in the number of microbes. November 26th Dakin's hypochlorite was applied every hour. Sterilization was attained November 29th. (∞ denotes infinity.—*Trans.*)

In order to get the best results mechanical preparation of the wound is necessary, and the reader should refer to what has been said before on this subject.

In regard to the application of Dakin's solution it is important to remember that the concentration of the antiseptic agent must be maintained; many failures in this treatment have been due to neglect of this important fact. Preservation of the concentration is best accomplished by continuous or intermittent application of the solution, which is weakened constantly by wound secretions and pus. In wounds that are badly infected prolonged application is necessary to bring about sterilization. With these facts before us, it is apparent that the simple application of dressings or packs, saturated with Dakin's solution, although the dressing may be changed several times during the day, can never accomplish sterilization.

Notwithstanding the fact that many surgeons have deemed

bacterial counts unnecessary to determine the sterility of a wound, or the time at which its closure can be successfully carried out, I am convinced that Carrel's method of making regular bacterial counts from smears taken from various parts of the wound is absolutely necessary in order to obtain the best results. Depage, who was one of the pioneers in this work and who has presented repeatedly the most convincing reports, adheres to the bacterial count as the criterion in closing wounds, and does not trust to the clinical appearance. In Evacuation Hospital No. 1 of the A. E. F. we followed the Depage technic absolutely and were able to duplicate his results. In this same hospital we tried the experiment of relying upon clinical appearance and the judgment of the surgeon, and at once our percentage of failures in retarded primary and secondary closure increased. Of course in many cases it was successful, due to the care in which the Carrel treatment had been carried out. I should certainly caution any surgeon against depending upon the clinical appearance of a wound until in a large number of cases he has used the bacterial count as an aid in the development of his clinical judgment.

Preparation of Dakin's Solution.—So much stress has been laid by both Dakin and Carrel on the preparation of the Dakin solution, and such unsatisfactory reports have been made because of improperly prepared solutions, that it seems wise to give here the proper method in detail. The following is Dakin's ordinary method of preparation: "140 grams of anhydrous carbonate of soda, or 400 grams of the crystallized salt, are dissolved in 10 liters of ordinary water, and 200 grams of chlorid of lime of good quality are added to it. The mixture is well shaken. At the end of half an hour the clear liquid is siphoned off and filtered through cotton. To the filtrate are added 40 grams of boric acid. The solution thus obtained may be used at once; it does not color phthalein in suspension in water."

This method was very simple, but Carrel points out that chlorid of lime "being of very variable composition, its content of active chlorin might vary from the normal to double the amount. Under the influence of humidity it forms compact masses, which, when agitated with the solution of carbonate of soda, are incompletely broken up, and only yield a portion of their hypochlorite. These are the reasons why defective solutions have sometimes been obtained while following conscientiously the procedure just described."

In order to obviate the objection just cited, the Daufresne method is recommended by Carrel, and is as follows:

"1. To prepare 10 litres of solution weigh out exactly the quantities of chloride of lime, carbonate of soda, and bicarbonate of soda determined when titrating the chloride of lime;

"2. Place in a 12-litre flask the chloride of lime with 5 litres of tap-water; shake vigorously two or three times and leave it over night;

"3. Dissolve the carbonate and bicarbonate of soda in 5 litres of cold water;

"4. Pour the solution of soda salts rapidly into the flask containing

the chloride of lime, shake vigorously for about a minute, and put it aside for the carbonate of lime to settle;

"5. After the lapse of about half an hour siphon the clear liquid and filter it through a double filter-paper, in order to obtain a perfectly clear product, which must be kept cool and protected from the light.

"An excellent means of stabilizing hypochlorite of soda consists in adding 1 : 200,000 of permanganate of potash (5 milligrammes per litre of filtered solution).

"The antiseptic solution is then ready for surgical use. It would contain 0.35 to 0.50 per 100 of hypochlorite of soda, with small quantities of neutral soda salts. It is practically isotonic with blood-serum."

As the variations in commercial chlorid of lime are marked, it is necessary to know the quantity of active chlorin contained in the chloride of lime with which one is working in order to use an amount calculated exactly, according to its titration.

The estimation is made in the following manner by Daufresne: "Weigh out an average sample of 20 grammes, stir it up in a litre of water as thoroughly as possible, and allow it to stand some hours. Measure off 10 c.c. of the clear liquid, add to it 20 c.c. of a 10 per cent. solution of iodide of potassium, 2 c.c. of acetic acid or hydrochloric acid, then to the mixture add drop by drop a decinormal solution of hyposulphite of soda (2.48 per cent.), up to decoloration. The number n of c.c. of hyposulphite employed, multiplied by 1,775, will give the weight N of active chlorine contained in 100 grammes of the chloride of lime."

Titration of chloride of lime (Cl %). (English degrees.)	Quantities to be used to obtain 10 litres of solution of hypochlorite of 0.475%:		
	Chloride of lime.	Carbonate of soda, anhydrous.	Bicarbonate of soda.
	Grms.	Grms.	Grms.
20	230	115	96
21	220	110	92
22	210	105	88
23	200	100	84
24	192	96	80
25	184	92	76
26	177	89	72
27	170	85	70
28	164	82	68
29	159	80	66
30	154	77	64
31	148	74	62
32	144	72	60
33	140	70	59
34	135	68	57
35	132	66	55
36	128	64	53
37	124	62	52

(From Carrel and Dehelly.)

"This estimation must be carried out for each consignment received. The above table drawn up by Daufresne gives directly, according to

the amount of active chlorin contained in the chloride of lime, the quantities of the reagents required to obtain automatically a correct solution."

"The determination of the quantity of soluble calcium in the chloride of lime would have a certain importance if one were not obliged, in order to obtain a product having some degree of stability, to use an amount of carbonate of soda far above that theoretically indicated. In fact, a solution prepared by the interaction of chloride of lime and salts of soda in theoretic quantities loses the whole of its hypochlorite in from fifteen to twenty days."

Dakin and Dunham (Hand-book of Antiseptics) described a method of preparing Dakin's solution by electrolysis of sodium chlorid solution and developed an apparatus which could be installed on board ships for the purpose of making the solution from sea-water. In some of the hospital ships I believe this was quite extensively employed. I had an opportunity to see its use in making a crossing on one of the British hospital ships and, as far as I could tell without examination of bacteriologic smears from the wounds, it seemed to be perfectly satisfactory.

Care should be taken to protect Dakin's solution from the light and the solution should be made fresh every few days. Carrel lays great stress upon the preparation of the wound by mechanical cleansing before starting the chemical sterilization. This technic, however, has already been given when speaking of débridement. When the wound has not been mechanically cleansed soon after the injury, but comes to the surgeon after infection has been established, as evidenced by the clinical symptoms of inflammation, Carrel believes it is better not to practice any surgical interference at once, but to substitute for drainage-tubes and packs, which have probably already been placed in the wound, several small instillation tubes and to start the continuous or intermittent irrigation. This is done with as little disturbance to the wound as possible and without anesthesia.

He says that "from a clinical point of view suppuration disappears after the lapse of a space of time varying from twenty-four hours to four days." In other words, he believes that it is better not to interfere during the primary stage of an acute inflammation, but to wait until the tissues have developed some normal resistance and the wound has become partially sterilized. When this has been accomplished, thorough mechanical cleansing will likely become necessary, but he says that wounds of the soft parts, as a rule, become aseptic under the influence of the antiseptic without the necessity of surgical operation. Of course this is not the case where foreign bodies are present, in many compound fractures, and in the presence of masses of devitalized tissue. In connection with the surgical cleansing of infected wounds he also says that "it must be borne in mind, however, that tissues which have already commenced to cicatrize during the stage of suppuration are impregnated with microbes and that reinfections are possible. Therefore operations involving the least possible amount of traumatism should be chosen."

It has become a well-known fact that secondary operations performed after partial or even complete cicatrization of the wound has taken place often result in an infection of the wound, notwithstanding the fact that there may have been no error in the aseptic technic of the operation. These infections are undoubtedly due to organisms which have been included in the cicatricial tissue and remain harmless and inert until

FIG. 107.—CONDUCTING OR "INSTALLATION" TUBE COVERED WITH A SHEATH OF BATH-TOWELING (*tissu éponge*). (Carrel and Dehelly.)

they are liberated and gain access to tissues which constitute a favorable nidus for their development. These infections are seen in the secondary operations performed for non-union or mal-union in compound fractures, in plastic operations for deformity, and in operations for the repair of nerve injuries. Because of the danger of infection Carrel suggests that after the performance of the secondary operation the wound be left open for a day or two, during which time the instillation of

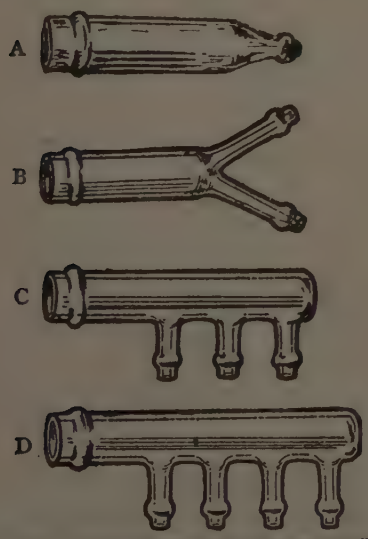

FIG. 108.—GLASS DISTRIBUTING TUBES (Gentile). (Carrel and Dehelly.)

A, Tube with one branch; B, tube with two branches; C, tube with three branches; D, tube with four branches.

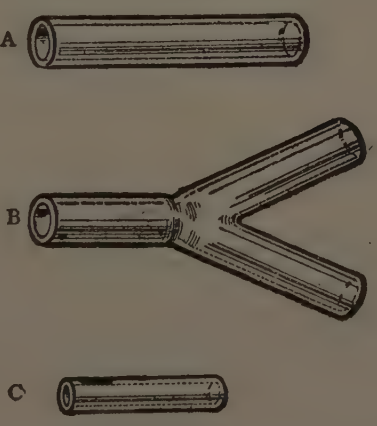

FIG. 109.—GLASS CONNECTING TUBES AND "UNIONS." (Carrel and Dehelly.)

A, cylindric tube of a length of 4 to 5 cm. and an interior diameter of 7 mm.; B, Y-tube with an interior diameter of 7 mm. These tubes unite the ends of rubber irrigating tubes. C, cylindric tube of a length of 3 cm. and an interior diameter of 4 mm. This tube serves to join up two small conducting tubes when it is necessary to add to the length of one of these tubes.

Dakin's solution should be carried out and the wound closed in two or three days. "In a word, during the cicatricial stage surgical interference practised in two stages, which are separated by a period of disinfection, is the surest means of avoiding disaster."

Technic of the Carrel Method of Sterilization.—Most surgeons are familiar with the Carrel apparatus, but the method of installing the treatment has been defective. The accompanying illustrations from

Carrel's book show very well how the tubes should be placed and also how their improper placement often results in failure.

FIG. 110.—AMPULE OR FLASK HOLDING A LITRE. (Carrel and Dehelly.)

FIG. 111.—PINCH-COCK (*Pince de Mohr à ressort*). (Carrel and Dehelly.)

Many surgeons are using an ordinary syringe for the instillation of the solution, but Carrel recommends that gravity is the preferable method. "We have completely given up the use of the syringe for

FIG. 112.—NURSE USING A PINCH-COCK AND SO INSTILLING ANTISEPTIC LIQUID. (Carrel and Dehelly.)

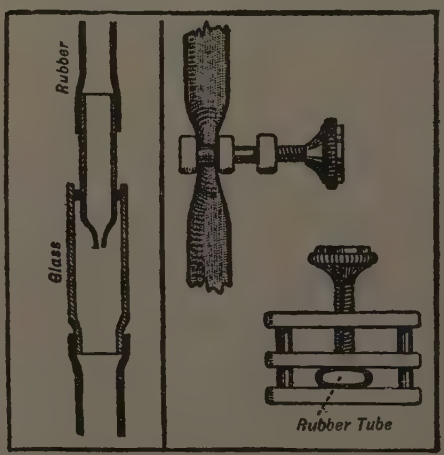

FIG. 113.—"DROP-COUNTER," GENTILE'S. SCREW PINCH-COCK (*Pince de Mohr à vis*). (Carrel and Dehelly.)

instillations. We use Gentile's syringe to test the permeability of the tubes in the course of doing the dressings."

In regard to the use of the different tubes and apparatus he says: "1. The appliance for continuous instillation should never be connected up with several tubes, nor with a tube perforated with several holes. As the output of a drop-counter is very small, all the liquid should flow through a single tube and emerge from a single hole in this

FIG. 114.—APPARATUS ARRANGED FOR DROP-BY-DROP INSTILLATION. (Carrel and Dehelly.)

a, Reservoir; *b*, *b*, irrigation tube; *c*, screw pinch-cock; *d*, drop-counter; *e*, distributing tube (Fig. 108, A); *f*, conducting tube with terminal orifice.

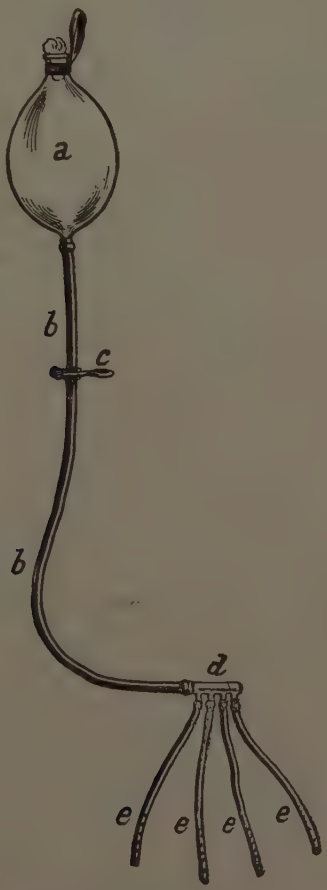

FIG. 115.—CARREL'S IRRIGATION APPARATUS. (Carrel and Dehelly.)

a, Reservoir for Dakin's fluid (*ampule or flask holding a litre*); *b*, *b*, the main distributing tube with a diameter of 7 mm.; *c*, the metal pinch-cock (*Pince de Mohr*); *d*, glass tube with multiple openings; *e*, *e*, *e*, *e*, final distributing tubes closed at distal end, but perforated with openings 1 mm. apart.

tube, the hole and the tube being dependent on gravitation. Consequently, instillation drop by drop should only be used for wounds which contain a single tube, perforated at its extremity (Fig. 114), or a single tube sheathed with 'tissu éponge' (bath toweling). 2. The apparatus for intermittent instillation can be connected up with four tubes perforated with tiny holes, or even, in certain cases, with eight. As

the yield of the irrigating tube is considerable, the liquid, at the moment the spring of the pinch-cock is released, spurts out from all the holes of all the tubes. As much as possible tubes of a length of 5 and 10 cm. should be used, especially if a single flask furnishes the liquid to eight tubes."

"It will not do to serve from the same cannula both simply perforated tubes and tubes sheathed in 'tissu éponge.' By reason of the different resistances the liquid would escape almost entirely by the simply perforated tubes."

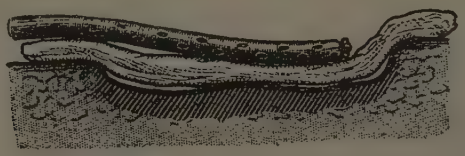

FIG. 116.—WOUND WITH SURFACE HORIZONTAL. (Carrel and Dehelly.)
Wrong method of placing the tube. The perforated instillation tube is on the surface of the compress.

"It is important to remember this difference in the action of the two forms of apparatus for continued instillation and for intermittent instillation, because, if a drop-counting appliance be used in connection with a system of general perforated tubes, no result will be obtained. The device for intermittent instillation is used much more frequently than the apparatus for continued instillation, because it allows a single irrigation reservoir to provide liquid for four or eight tubes at once (Fig. 115). It is, therefore, applicable to all large wounds.

"If a tube closed at one end and pierced with small holes is placed in a 'seton' wound whose axis is almost horizontal, liquid readily remains in the wound (Fig. 121). But if the axis of the seton is vertical,

FIG. 117.—WOUND WITH SURFACE HORIZONTAL. (Carrel and Dehelly.)
Right method of placing the tube. Tube in contact with the wound and covered with a gauze compress.

the liquid escapes by the inferior opening immediately it is injected. Therefore, sometimes, in these cases a tube wrapped in 'tissu éponge' is used. This absorbent fabric (Fig. 107) distributes the fluid over the surface of the wound and keeps it there for a period more or less prolonged."

"Fresh wounds nearly always bleed. If tubes pierced with small holes be placed in a wound containing fresh blood, the tube will be filled with it, the blood will coagulate, and the lumen of the tube will be obliterated. It is essential, in fresh wounds, to arrest hemorrhage thoroughly before arranging the tubes, and to verify their permeability

with care before continuing the dressing. Fresh wounds having no secretion or very little, tubes sheathed in absorbent fabric may be applied to their surface without inconvenience. For the same reason gauze is less harmful on fresh wounds than on wounds which are suppurating."

"The presence of pus on a wound is an indication that tubes surrounded with absorbent tissue may not be used, because this fabric immediately becomes saturated with pus. For the same reason 'wicks' and gauze compresses are used as little as possible, and tubes multiplied. Gauze may be used at the orifice of the wound. But all the diverticula should contain tubes and not gauze. It is advisable to have the tubes more numerous than in a fresh wound of the same dimensions."

Dressing.—One of the most important things in this method of sterilization is the care with which the dressings are done. It is only by carrying them out in the most thorough and aseptic manner that the success of Carrel, Depage, and others can be duplicated.

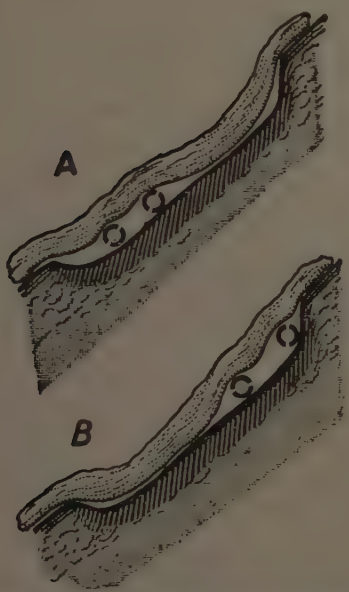

FIG. 118.—WOUND WITH SURFACE INCLINED. (Carrel and Dehelly.)

A, Tubes placed the wrong way, along the lower border of the wound. B, Tubes placed the right way, along the upper border of the wound.

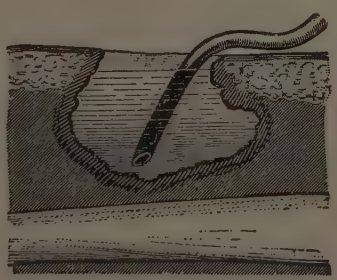

FIG. 119.—SHOWING CARREL'S METHOD OF USING DAKIN'S SOLUTION IN AN ANTERIOR WOUND AND KEEPING THE WOUND FULL OF SOLUTION LIKE A CUP, SO AS CONSTANTLY TO ATTACK THE INFECTING BACTERIA. (Carrel and Dehelly.)

After the tubes have been properly placed in the wound gauze compresses soaked in Dakin's solution are placed in such a way as to fix the tubes on the surface of the wound, allowing them to pass out through the dressings, so that the instillation can be carried on without disturbance of the dressings.

It is important that all openings in the tubes should lie within the wound, otherwise the solution will largely escape into the surrounding dressings. The skin about the wound should be covered by strips of gauze sterilized in vaselin to prevent irritation. This irritation, however, can be largely avoided by not using too much of the solution at the time of instillation.

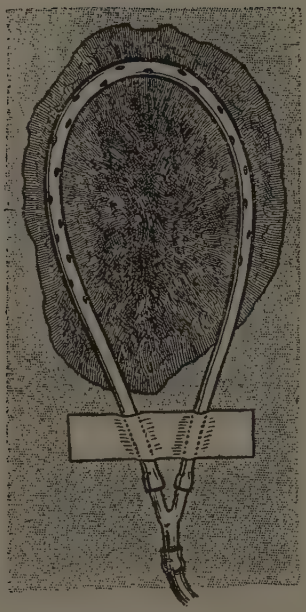

FIG. 120.—SURFACE WOUND. (Carrel and Dehelly.)

The instillation is made by means of a tube perforated in its middle portion, whose ends, fixed to the skin by a strip of adhesive plaster, are joined by a Y-shaped distributor.

FIG. 121.—"SETON" WOUND IN THE INTERIOR OF WHICH IS PLACED AN INSTILLATION TUBE PERFORATED WITH SMALL HOLES AND WHICH PASSES THROUGH THE DRESSING AT ITS UPPER PART WITHOUT BEING CONSTRICTED. (Carrel and Dehelly.)

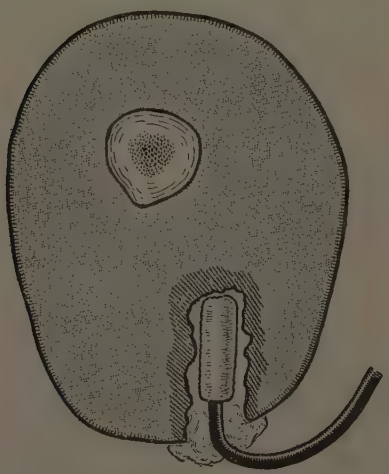

FIG. 122.—MODE OF IRRIGATING A WOUND IN A POSTERIOR POSITION. (Carrel and Dehelly.)

Observe that the distributing tube is here necessarily surrounded with toweling, otherwise the fluid would escape almost immediately. This toweling should be firmly sewed to the distributing tube (*b*, Fig. 115, p. 393) by silk and not by catgut, so that it may not become detached and be left in the wound.

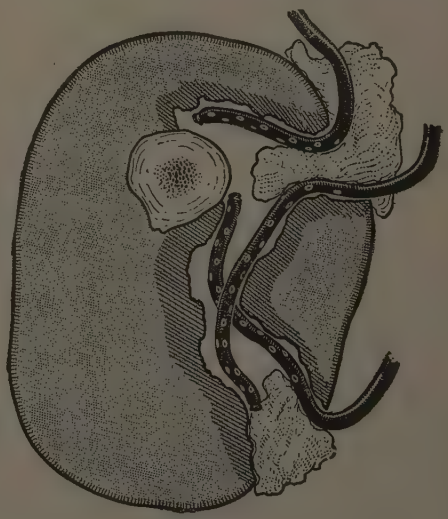

FIG. 123.—IRREGULAR WOUND OF THE THIGH (Carrel and Dehelly.)

Two tubes are placed in the wound anteriorly and one posteriorly. These tubes are applied to the surface of the tissues. The *correct* way of placing the distributing tubes so that the Dakin fluid comes directly in contact with all the surfaces of the wound. They are kept apart by gauze packed between them in the opening of the wound.

The accompanying illustration (Fig. 126) shows Carrel's dressing which tends to absorb the excess of the solution and also permit easy evaporation. He warns against the use of water-proof material to

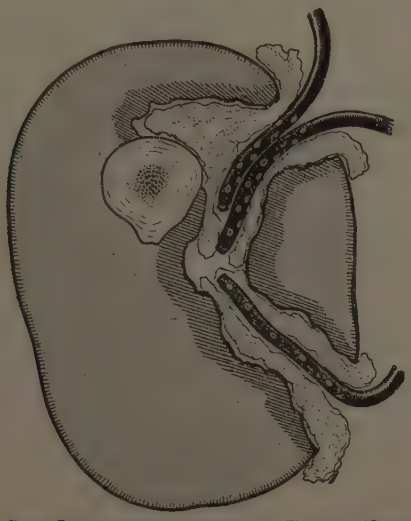

FIG. 124.—THE SAME IRREGULAR WOUND OF THE THIGH. (Carrel and Dehelly.)
Showing the *improper* way of placing the distributing tubes. Instead of being in contact with the tissues they are in contact with the gauze which fills the wound.

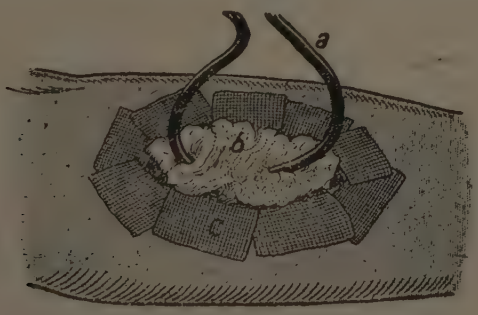

FIG. 125.—DRESSING. (Carrel and Dehelly.)
a, Conducting tube kept in the wound by gauze placed in the orifice; *b*, squares of gauze sterilized in vaselin placed on the skin around the wound.

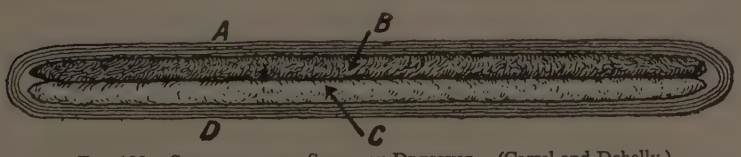

FIG. 126.—SECTION OF THE SHEET OF DRESSING. (Carrel and Dehelly.)
A, Gauze; *B*, carded (non-absorbent) cotton-wool; *C*, absorbent cotton-wool; *D*, gauze.

prevent wetting of the bedclothing. The use of these impermeable materials I am sure has been the cause of skin irritation in many cases, as they prevent evaporation. The dressing is only renewed once a day

unless it becomes saturated, when the outer layers can be changed. The dressing is done entirely with instruments, and care should be

FIG. 127.—DRESSING APPLIED AROUND A COMPOUND FRACTURE OF THE LEG AND FASTENED BY SAFETY-PINS; THE DISTRIBUTING TUBE IS FIXED TO THE PLASTER APPARATUS BY SAFETY-PINS. (Carrel and Dehelly.)

taken to see that the tubes are maintained in the proper position and that the openings in them are not blocked. No washing of the wound is done, but simply a change of the gauze.

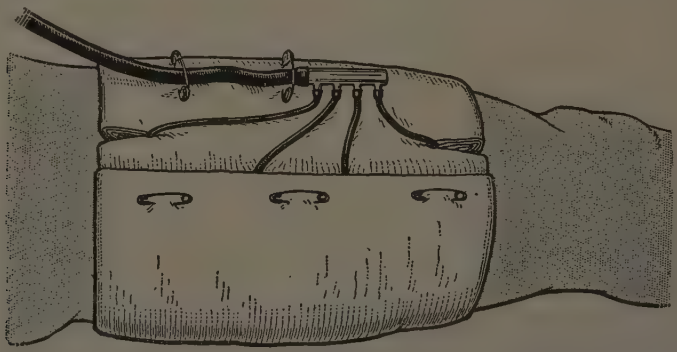

FIG. 128.—POSITION OF THE DISTRIBUTING TUBE ON THE SURFACE OF THE DRESSING. (Carrel and Dehelly.)

The conducting tubes penetrate the dressing either at the point where the end of the layer of cotton-wool and gauze overlaps or through windows cut with scissors.

Between dressings the instillations of the solution are made every two hours, day and night, until all bacteria have disappeared from the

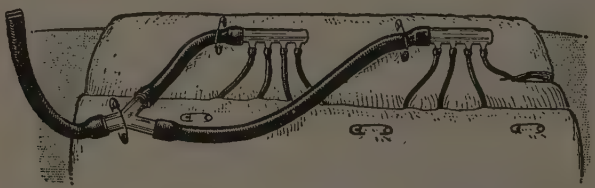

FIG. 129.—ARRANGEMENT ON THE SURFACE OF A DRESSING OF A Y-CONNECTING TUBE, AND OF TWO DISTRIBUTING TUBES WITH FOUR BRANCHES. (Carrel and Dehelly.)

smears, which are taken every second or third day. Carrel points out certain errors of technic, the first being insufficient penetration of the

liquid. He states that if the diminution in the number of microbes found in the smears does not progress steadily, there is some failure in the technic. It may be due to the fact that the solution does not reach all the infected regions; this may be caused by the detachment, obliteration or kinking of a tube, or to the fact that the tube is not placed in some diverticulum of the wound. It may also be due to the fact that the fluid does not flow in all the tubes. This may be avoided by following directions already given in regard to size of tubes and method of instillation.

Another error of technic is to use an excessive quantity of the solution, resulting in wetting of the bed and irritation of the skin. This can be easily avoided by regulating the amount of fluid which is injected through the tubes.

A third error is too much pressure due to too great elevation of the reservoir, or to the fact that there is not sufficient space between the tube and the wound edges to permit a ready reflux of the fluid, and causes distress to the patient at each instillation. The correction of this error is obvious.

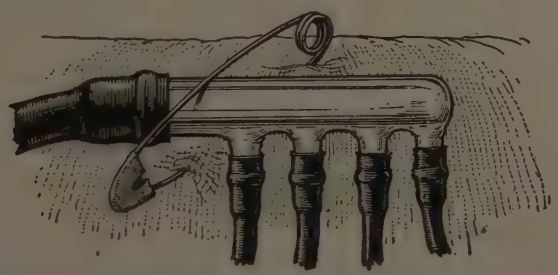

FIG. 130.—METHOD OF FIXING A DISTRIBUTING TUBE TO THE SURFACE OF A DRESSING. (Carrel and Dehelly.)

Clinical and Bacteriologic Examination of Wounds.—Although far from denying the value of clinical observation in regard to bacterial activity in a wound, Carrel says that it permits "one to presume what may be the state of the wound, but yields no certainty. In fact, wounds whose margins present neither edema nor redness, whose surface is covered with even granulations, and whose secretion is of the slightest, may still be strongly infected. The following case is an example of this: After section of the deep femoral by a shell wound a free incision had exposed the sheath of the sciatic nerve, which was filled with blood. After a few days this extensive wound had an excellent appearance. The man was in no pain and had no pyrexia. A little lemon-colored serum flowed from the wound. It was collected in a pipet. But the general appearance of the wound was so favorable that it was closed with strapping, without waiting for the results of the bacteriologic examination. That evening the case had a temperature of 40° C. (nearly 104° F.), and the wound had to be taken down. The surgeon then asked for the bacteriologic report, and learned that the transparent liquid contained chains of streptococci. Hence in certain

cases clinical observation is absolutely impotent to instruct us as to the real condition of a wound."

"Wounds also are met with covered with grayish granulations and with a puriform liquid, which are aseptic, and which may be sutured with success."

"Clinical observation should be looked upon as an adjunct to the bacteriological examination. Wounds identical in appearance, from the clinical point of view, may be in very different microbial conditions. Between a wound which yields five or six microbes per field of microscope, and a wound which contains none, usually there is no appreciable clinical difference. All the same, the few microbes which remain on the surface of the first wound can retard by one-half the rapidity of its cicatrization. The presence of these microbes is important, for it prevents suturing. Hence the aid of the laboratory is constantly needed to ascertain the progress of sterilization."

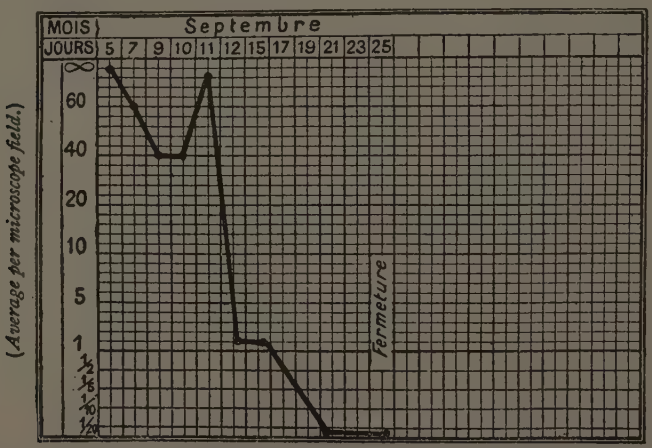

FIG. 131.—MICROBIAL CHART. (Carrel and Dehelly.)

In the upright columns are noted the number of microbes found per microscope field, varying from infinity to 1 and from 1 to $\frac{1}{20}$. A twentieth implies one microbe per twenty fields of the microscope. The upper horizontal column marks the date.

Comment has already been made upon the value of clinical observation without bacterial counts, and it is only fair in undertaking this method of treatment to follow it conscientiously and in detail. After observing thousands of wounds with the idea of determining whether they might be closed, I must confess that I learned to place reliance nearly altogether on the bacterial count; and this has been the experience of hundreds of practical surgeons. There might be some question as to the importance of keeping bacterial charts for each case, but I believe that doing so will stimulate assistants and nurses in the proper method of dressing and instillation of the fluid. It is extremely important that assistants and nurses, and even the patients themselves, should appreciate the necessity of detail, and nothing demonstrates to us so well what is, or is not, being accomplished as a bacterial chart.

During about the first twelve hours it is not likely that bacteria will be found in the smears, especially if the wound is oozing at the

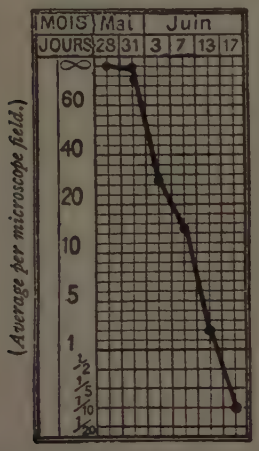

FIG. 132.—CURVE REPRESENTING THE STERILIZATION OF THE WOUND IN A CASE. (Carrel and Dehelly.)

It shows that the microbes, which were in great number on May 31st, diminished and practically disappeared by June 17th.

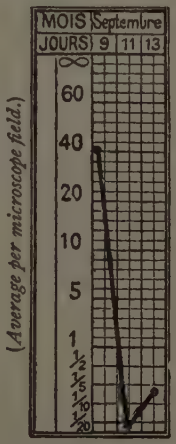

FIG. 133.—RIGHT KNEE. WOUND EXTERNAL. (Carrel and Dehelly.)

Typical curve of sterilization of a wound of the soft parts. The wound, which contained 40 microbes per microscope field at the time of the first examination, was surgically sterile two days later.

time. Smears should never be taken from a bleeding surface, and if the instillation of Dakin's fluid is continuous, it should be interrupted

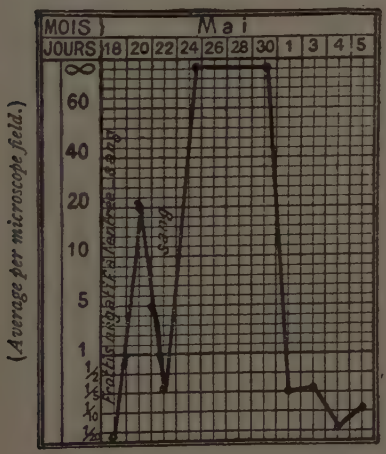

FIG. 134.—COMPOUND FRACTURE OF TIBIA. (Carrel and Dehelly.)

Sterilization curve of a highly comminuted fracture of the tibia. The first smear was negative because the wound was fresh. The third was equally so because of the presence of blood. Sterilization the ninth day.

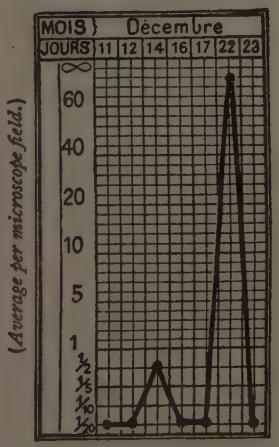

FIG. 135.—BURN. (Carrel and Dehelly.)

Curve showing a reinfection of cutaneous origin upon a surface wound previously aseptic.

for two hours at least before taking the smears. Carrel lays great stress upon the importance of not taking the smears from a portion of the

wound where there is any bleeding. The smears should be taken from all suspicious looking parts of a wound and also from its deepest portions. It must be remembered that bacteria are much more apt to be found about fragments of bone, foreign material, and necrotic tissue. In certain wounds the bacteria are much more readily destroyed than in others, as is shown by the accompanying charts. "Each slide is held between the thumb and index-finger, and passed three times through the flame of a Bunsen burner, the smear being turned toward the flame. Then it is placed on a glass support and receives a few drops of carbolized thionin. After half a minute it is washed with water and put aside to dry."

"The disappearance of microbes from the smears by no means implies that the wound is really aseptic. It simply indicates that the

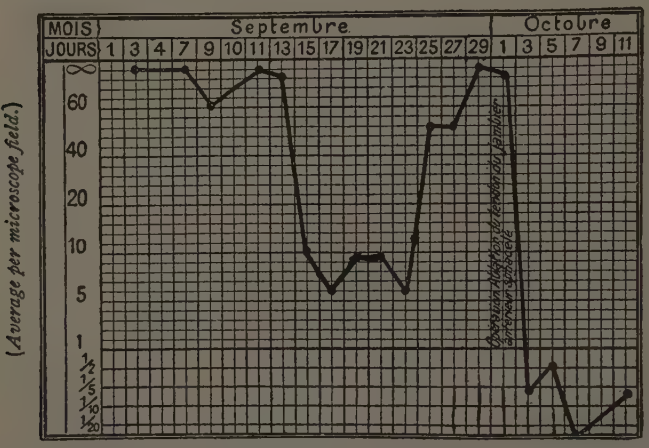

FIG. 136.—DEEPLY INFECTED COMPOUND FRACTURE OF THE TIBIA BECOMING STERILIZED IN A PARTIAL MANNER. (Carrel and Dehelly.)

The reinfection which occurred from the 23d to the 29th decided us to remove a fragment of sphacelated tendon which had been acting as a foreign body. Sterilization was obtained in two days.

degree of sterility compatible with closure of the wound has been attained. We are seeking, in fact, surgical asepsis, not bacteriological asepsis. In the majority of cases the secretions of wounds whose smears no longer yield a microbe still give positive cultures. Certain writers, *e. g.*, Policard, even believe that chemical sterilization never achieves absolute asepsis of a wound. However, by the aid of a precise technic, the surface of a wound can be rendered so aseptic that cultures from its secretions remain sterile. But this degree of asepsis is of no practical interest."

No apology is offered for the extensive quotations from Carrel's book because his method of treating infected wounds has so commonly failed in the hands of those who have carried out the treatment indifferently.

Other Methods of Sterilizing Infected Wounds.—A great many

other antiseptics, both new and old, were used extensively to disinfect war wounds, and a number of them have proved of great value, but none of them have been used so extensively as Dakin's solution, nor have the results which they produced, I think, equaled those obtained by the Carrel-Dakin method in the hands of surgeons who have carried out this method in detail.

Dichloramin-T (Toluene-parasulphondichloramin).—Dakin, Lee, Sweet, Hendrix, and Le Conte[7] made a report to the American Surgical Association on the use of dichloramin-T in the treatment of infected wounds. They called attention to the fact that the Carrel-Dakin treatment has certain objections, and that the solutions must be made with extreme care, that they are unstable, and must be freshly made. Also that they irritate the skin if they are allowed to remain in contact with it for any length of time. They add, however, that "at Compiègne and La Panne, Carrel, Dehelley, and Depage have evolved a technic which will minimize this annoying irritation if carried out in its minutest detail; and from our personal experience the success or failure of the method depends entirely on the degree of perfection with which the details of this technic are mastered and carried out."

The method here referred to has been described on the foregoing pages.

In describing dichloramin-T they say: "We offer as a solution of the serious obstacle of skin irritation of the usual chlorin preparations a practically stable, non-irritating, synthetic double chloramin compound, toluene-parasulphondichloramin, or dichloramin-T; this solution to be used in strengths varying from 5 to 10 per cent. (from twenty to forty times the mass of germicide ever present in the usable concentrations of hypochlorites), dissolved in a chlorinated oil in order that the germicides will be slowly liberated over a period of from eighteen to twenty-four hours instead of from thirty minutes to one hour, as with the hypochlorite solutions."

"The technic of its application is simplicity itself, in contradistinction to that of Carrel, Dehelley, and Depage. After a careful surgical preparation of the wound at the primary dressing, and excision of all foci of infection and of devitalized tissues, the solution is applied on surface of wounds with an atomizer in the form of a spray. In deep wounds the cavities are filled with the liquid. When dependent drainage exists because of the location of the wounds or when it has been purposely made, the lower opening is temporarily closed with gauze and then the cavity is filled with the oil, thus covering all the wound surfaces. The dependent drainage is then re-established by removing the temporary gauze obstruction."

"We have found that it is necessary to apply the oil but once in twenty-four hours, and the wounds should be covered only with a few layers of gauze to avoid the absorption of the oil by the dressings."

The following is their description of the preparation of dichloramin-T: "The following details were worked out for Chattaway's method of preparation: Chlorinated lime (from 350 to 400 gm.) of good quality

(of 25 per cent. or more of available chlorin) is shaken with 2 liters of water in a shaker for half an hour, and then the mixture allowed to settle. The supernatant fluid is siphoned off and the remainder filtered."

"Powdered toluene-parasulphonamid, 75 gm. (the crude product may be used), is then added to the whole of the hypochlorite solution and shaken until dissolved. The mixture is filtered, if necessary, placed in a large separating funnel, and acidified by the gradual addition of acetic acid (100 c.c.). Chloroform (about 100 c.c.) is then added to extract the dichloramin, and the whole is well shaken. The chloroform layer is tapped off, dried over calcium chlorid, filtered, and allowed to evaporate in the air. The residue is powdered and dried *in vacuo*. It is sufficiently pure for most purposes without recrystallization."

"The sodium toluene-parasulphochloramin, which is sold under the trade name of chlorazene, may be used instead of the toluene-parasulphonamid."

"*A Second Method of Preparing Dichloramin-T.*—Fifty gm. of paratoluenesulphonamid are dissolved in 500 c.c. of water, and 100 gm. of sodium acetate and 100 c.c. of chloroform are added. The container is immersed in cold water, and a rapid stream of chlorin is passed in until the mixture is saturated. The mixture is allowed to stand a few hours, and if the odor of chlorin disappears, more of the gas is passed in. If necessary, more chloroform can be added to dissolve the dichloramin. From this point the procedure is the same as in the preceding method."

"*Preparation of Chlorinated Eucalyptol.*—Eucalyptol (U. S. P.), *not* eucalyptus oil, must be used; 500 c.c. are treated with 15 gm. of potassium or sodium chlorate and 50 c.c. of concentrated hydrochloric acid. After twelve hours the oil is well washed with water and sodium carbonate solution. Dry sodium carbonate is added to the oil, and the mixture is allowed to stand twenty-four hours. It is then filtered and dried with a little calcium chlorid."

"*Preparation of Chlorinated Paraffin Oil.*—500 c.c. of commercial liquid petrolatum are treated with 15 gm. of potassium or sodium chlorate and 50 c.c. of concentrated hydrochloric acid. The mixture is exposed to the light and allowed to stand over night. It is then put into a separatory funnel, and washed successively with water, sodium carbonate solution, and water. The opalescent oil is tapped off, a lump or two of calcium chlorid and 5 gm. of charcoal are added, and the oil is filtered with suction."

Their contribution closes with the following conclusions:

"1. Dichloramin-T is a non-irritating, synthetic germicide, and corresponds to the antiseptic chloramin substances found in minute quantities when active chlorin of the aqueous hypochlorite solutions is brought into contact with the exudate of suppurating wounds.

"2. Dichloramin-T can be used in strengths of from twenty to forty times greater than is possible with the hypochlorites, and is an oily solution which makes possible the slow diffusion of the germicide over a period of from eighteen to twenty-four hours, instead of a rapid

disappearance in from thirty minutes to one hour, as with the hypochlorites.

"3. Its use is as simple as the application of the tincture of iodin, and we can see no reason why it cannot be used to replace iodin as a primary dressing. In our experience it is just as effective as a germicide, and is without the destructive effect on the tissue cells. We have had the opportunity of using it in this way at the primary operation in seven wounds involving soft tissues, tendons, joints and bones, and have not failed to have primary union. One case, a compound fracture of a metacarpal with severed extensor tendons, did not receive treatment until three hours after the injury.

"4. The chlorin in dichloramin-T, as in the hypochlorites, has the power of dissolving dead tissues. Hemorrhage, therefore, must be stopped by ligation, else the clot will dissolve and secondary hemorrhage may follow.

"5. One should not depend on a chemical agent to perform, in the treatment of suppurating wounds, that which can and should be done quickly and thoroughly by mechanical means. Neither chemistry nor bacteriology can or should be expected to replace the mechanics of surgery. At the best these chemical germicides can react only on the bacteria with which they actually come in contact, which means a very superficial process of infection. There, at the primary operation, all foci and devitalized tissues must be removed when possible by surgical procedures. Finally, adequate drainage, dependent if indicated, must be provided."

As a result of this paper and many subsequent ones by a number of surgeons, but particularly by Lee and Furness[8] and Dunham,[9] this agent has been very extensively used, particularly in America, and through the efforts of Sweet it was used quite extensively in the British Army. From what I have seen of its use I am convinced that it will supplement, but never supplant, the use of Dakin's solution. In a very able paper entitled "Antiseptics," to be published in Progressive Medicine, Lee makes the following summary, which I think is a fair statement of the relative values of the chlorin group of antiseptics:

"(1) The direct germicidal action of all the chlorine antiseptics depends upon the chlorine which they liberate when in the human tissues and upon the combination of the chlorine with bacterial proteins.

"(2) The solution of sodium hypochlorite can only be used clinically in very weak dilutions because of the rapidity with which it liberates chlorine requires the living tissues to provide ample protein to protect themselves against its destructive action. The safeguard against the destructive action of chlorine is the sufficient mass of chemically available protein.

"(3) The solutions of sodium hypochlorite, unlike the chloramines, dissolve dead and devitalized tissues, and thus exert an indirect antiseptic effect by removing bacterial culture material.

"(4) Taylor and Austin[10] found from their experiments that Dakin's hypochlorite solution had the power of dissolving necrotic tissue, pus,

and plasma clot in the concentration and reaction used clinically. Chloramin-T and dichloramin-T did not exhibit this action.

"(5) The chloramines are more stable compounds of chlorine than the hypochlorites, and therefore can be used in greater concentrations or larger germicidal masses. They act practically as reservoirs from which chlorine is automatically given off as the tissues present the necessary reacting substances.[9] The reaction of these organic chlorine compounds when in the tissues do not form the solvent mineral salts of the type of sodium hydroxide.

"(6) The hypochlorite solutions are indicated where there are large masses of dead and devitalized tissue or profuse tissue exudate which cannot be removed by mechanical means, *i. e.*, massive traumatic wounds and empyema. They should not be used where such protein barriers are not present or applied to tissues poorly supplied with blood.

"(7) The chloramines are indicated where there is but little if any dead tissue, and where the wound exudate is moderate in amount. Their only value is as a germicide. They liberate their chlorine, when in the human tissues, slowly over a period of from three to twenty-four hours, and in sufficient quantities to combine automatically with the bacterial and other proteins presented by the wounds."[8]

Lee and Furness[8] describe the preparation of a paraffined mosquito netting, which is used to prevent adherence of the dressings to the wounds, and which also permits free drainage from the wound surfaces. Material of this kind was used quite extensively in the Belgian hospitals during the war, and I had the opportunity of dressing a number of patients, after they had reached a British Base hospital, whose wounds had been covered with a paraffined mesh, and there was certainly no comparison between the suffering which they endured during the dressing and that suffered by other patients, where gauze came in contact with the raw surfaces. I quote Lee and Furness's method of preparing this material because it should be used more extensively in the dressing of open wounds: "A good quality of mosquito netting with a $\frac{1}{16}$-inch mesh is used, or fly netting, $\frac{3}{32}$-inch mesh. As purchased it is stiffened or 'sized' and we have found this to be a decided advantage, for if the starch or 'sizing' is removed by washing, the thread will absorb too much of the paraffin and the mesh will be filled with wax, which prevents drainage. The netting is cut into strips 4 by 6 inches, being a convenient size, and 10 pieces are placed in muslin wrappers and a package made, as is done with gauze sponges. These packages are then sterilized in the usual way, steam under pressure of 15 pounds.

"Paraffin wax, melting at 45° C.—ambrine, paresine, redintol, or cerelene—is then melted on a water-bath in a flat agate tray. The tray should be about half-filled with the melted paraffin. When the wax is thoroughly melted the previously sterilized netting, grasped at the two corners of one end by two sterile thumb forceps, is slowly drawn through the melted wax. The threads will quickly absorb the required amount of paraffin in about one minute, and then the strip is held, by means of the same forceps, vertically over the hot surface of the melted paraffin

until the excess wax has drained away and the mesh is everywhere open. The strip is then moved away from the hot tray and held for a few seconds in the air to cool, after which it is placed, in piles of ten, in sterile muslin wrappers as previously described."

Chloramine-T Paste.[11]—Both Dakin and Carrel have shown by experimental work that any antiseptic paste used for the sterilization of wounds must be free of fat and grease, as when these are present there is no appreciable effect upon the bacteria in the wound. Daufresne has succeeded in preparing a paste containing 8 per cent. sodium stearate and from 4 to 15 parts per 1000 of chloramin-T. This paste is applied to the wound by means of a sterilized wooden spatula. This paste is designed only to keep a wound sterile which has already been sterilized by Dakin's solution, or to be used in slightly infected wounds. Carrel says it should be applied to those wounds where there is a small quantity of secretion, little or no necrotic tissue, and little or no infection. Before applying the paste the wounds are cleansed with neutral oleate applied with cotton swabs held by forceps; the oleate is removed with sterile water and the wound thoroughly dried; and the paste is then applied over the wound and beyond the wound edges and covered with dry gauze. The dressing is repeated every twenty-four hours. The following is a part of the summary of this communication: "Sodium stearate has no effect upon the bacteriological condition of a wound, but the addition of 4 parts per 1000 of chloramin-T renders it antiseptic. Experiments enabled us to compare the action of sodium stearate alone with that of sodium stearate containing 4 parts per 1000 of chloramin-T. Wounds which had been previously sterilized could be maintained in an aseptic condition by 4 parts per 1000 of chloramin-T, although in some cases reinfection occurred. For this reason the concentration of the chloramin-T was increased.

"Surface wounds, deep-seated wounds, and osseous cavities, which had previously been either completely or almost completely sterilized, could be maintained for a few days or even weeks in a condition of surgical asepsis by the use of a paste containing 7 and 10 parts per 1000 of chloramin-T. Slightly infected wounds were sterilized in the same manner.

"Next it was attempted to sterilize wounds which were suppurating and more or less infected, and in some cases accompanied by fracture. This attempt was probably successful because the wounds used for the experiment showed but slight quantities of secretions and only a shallow layer of necrotic tissue.

"It is useless to attempt to sterilize severely infected wounds with paste, for the volume of chloramin-T that can be applied is too limited. A large volume of an active substance is required to sterilize a wound which secretes great quantities of pus, for owing, on the one hand, to the dilution of this substance with the secretions, and, on the other, to its combination with the proteins contained in the pus, the concentration of the antiseptic is rapidly diminished. For these reasons it is essential that the antiseptic solution should be constantly renewed, so

that the concentration may be sufficiently strong to effect the destruction of the bacteria. Therefore the chloramin-T paste cannot sterilize a severely infected wound."

When I visited Carrel's Hospital in December, 1917, I found that this paste was being used very extensively on *superficial* wounds, and the bacteriologic charts showed that the paste in this type of wound caused a fall in the bacterial count nearly as quickly as Dakin's solution, and, of course, its application was much simplier, as it was applied only once a day.

Flavine and Brilliant Green.—Browning, Gulbransen, Kennaway, and Thornton[12] are largely responsible for the use of dyes as antiseptics. One of the most extensively employed dyes is flavine (diaminamethylacridinium chlorid). One of the advantages claimed for this agent is that its bactericidal power is not interfered with by the presence of blood-serum. The claim is set forth that it is 20 times more powerful than mercury perchlorid and 800 times more powerful than carbolic acid or dichloramin-T, and also that it exerts no toxic action. It is recommended for use in a concentration of 1 : 1000. It is not precipitated by the addition of either sodium chlorid or sodium citrate solution.

The early claims for flavine and brilliant green, however, have not been generally realized, and certainly their use would seem to have definite limitations.

Both in a British C. C. S. and some of the British Base Hospitals I had the opportunity of observing the effects of these agents and am rather inclined to believe that many of the good results ascribed to their use was, in reality, due to a careful débridement.

Wallace and Fraser[13] state that the great expectations concerning the therapeutic value of these agents has not been entirely realized, and that under their use after a few days "diminution of sepsis in the wound ceases to be progressive, the granulations become pale and flabby, and the wound surface becomes covered with a gelatinous-looking pellicle." They state that the objections can be overcome by the use of eusol, the British substitute for Dakin's solution.

Pearson,[14] after discussing the use of flavine, reaches the following conclusions: "In cases where infection and sepsis are active and uncontrolled, the use of flavine following suitable operative measures has no beneficial effect on the subsequent progress of the cases so far as the control of sepsis is concerned. Any slight differences observed were unfavorable.

"In cases where sepsis has already been controlled and repair has begun, flavine acts injuriously, chiefly by producing an unhealthy granulating surface.

"While these conclusions do not prove that flavine may not possess powerful germicidal properties in certain experimental conditions, I believe that they show that its clinical use is not attended with good results. Since completing my observations I have entirely abandoned the use of flavine in my work.

"These conclusions were reached before the recent papers by Capt. A. Fleming[15] and Prof. R. T. Hewlett[16] were published, in which grave doubts are cast on even the experimental bactericidal powers of flavine. My observations furnish a clinical compliment to the laboratory work of these authors."

Bowlby,[17] in his introduction of the report to the Medical Research Committee by Drummond and McNee, states that flavine is incapable of sterilizing wounds and that the agent did not interfere with the growth of anaërobic organisms. He also states that the healing by granulation is very slow under these agents. He approves its use as a first dressing in large open wounds.

Crile[18] was very favorably impressed by the results obtained with flavine in war wounds, and is using it (1 : 5000) in civil practice in order to prevent infection of clean wounds when it is necessary to leave the wound open.

A number of surgeons were impressed by the clean appearance of the open wounds which had been packed with gauze saturated in flavine at the advanced hospitals upon their arrival at the base hospitals. But again I would suggest that at the time flavine was introduced careful débridement had largely taken the place of the old haphazard excision of wounds, and that the good results were attributable largely to this fact.

A number of further references to contributions on the use of flavine will be found in the Bibliography.[19]

B. I. P. Paste.—Under this abbreviation Rutherford Morison[20] described a paste composed of bismuth subnitrate 8 oz., iodoform 16 oz., and liquid paraffin 8 fluidoz., which he used very extensively in infected wounds, particularly war wounds. He and others have presented many communications on the use of this paste, and probably it was as extensively used in the British service as any agent except eusol. The following is Morison's description of the preparation of the paste: "The powders are mixed together in a mortar and the liquid paraffin incorporated. The quantity of liquid paraffin required varies according to the bulk of the powders, the bismuth in particular being liable to considerable variation in bulk. A sufficient quantity should be added to form a paste. It is then advisable to rub down the paste in small quantities at a time on a slab with a spatula, to insure freedom from grit and dry particles of powder."

After the proper mechanical cleansing of the wound, Morison advises that the entire surface be covered with the paste, which is rubbed well into the tissues with dry gauze, *the excess being removed*, leaving only a thin covering over the raw surfaces. A sterile dry dressing is applied which is not removed for days or weeks if the patient is free from pain and evidences of infection.

Morison and others have called attention to the risk of both iodoform and bismuth poisoning, and he says that they have been due to the fact that in the beginning the paste was used too generously. If

properly employed, the *excess being removed*, it is stated that this danger is eliminated.

When working in a British C. C. S. I used bipp in a great many superficial wounds, and saw it used in all sorts of wounds. My impression is that it is a good dressing where there is no hope of retarded primary closure. Many surgeons, however, became so impressed with its use that the paste was used over the wound surfaces before primary closure, and some smeared the wound surfaces with it when doing secondary closure. My own feeling about bipp is the same as that of many other antiseptic agents, namely, that if we are dealing with a wound which has been thoroughly débrided, or with one which has been completely sterilized, complete closure can be done with as good prospects of prompt union without these agents as with them. In England I saw quite a number of wounds closed secondarily, in the treatment of which bipp alone had been used.

Salt Solutions.—Wright[21] discusses in a very interesting way the uses of salt solution in varying strengths in the treatment of infected wounds. It is owing largely to him that the salt solutions were used so extensively in the treatment of war wounds. The hypertonic salt solution (5 per cent.) he says will attract water, and unless a membrane which is impermeable to albumin is interposed, the outflowing current of water will bring away with it the protein substances which it holds in solution. "This means that hypertonic salt solution applied to tissues lying bare in the wound (or to granulating surfaces) will operate as a *lymphagogue*, drawing out from the infected tissues lymph which has spent all its antibacterial energy, and drawing into the tissues from the blood-stream lymph inimical to microbe growth."

When brought into contact with leukocytes the hypertonic solution will disintegrate them, set free the tryptic ferment they contain, and inhibit the action of this ferment which is set free in the wound. It also inhibits coagulation and prevents the sealing up of orifices through which lymph pours into the wound. It also inhibits leukocytic emigration into the wound and prevents phagocytosis in the cavity of the wound, and will inhibit microbic growth.

Normal salt solution produces a positive chemiotactic action on leukocytes, and when applied to a wound brings the leukocytes to the surface. Normal salt solution does not interfere with the activity of trypsin or inhibit blood or lymph coagulation, phagocytosis, or microbic growth.

Wright explains in detail the practical application of what has been learned regarding the physical and physiologic action of the solutions of sodium chlorid in the treatment of wounds. The hypertonic solution is first employed in infected wounds when the tissues are "lymph-bound, infiltrated, and sloughing."

"The striking feature here will be the outpouring of lymph. But there will at the same time: (*a*) in the depth of the tissues, (*b*) on the surface, and, (*c*) in the cavity of the wound, be evoked other reactions which cannot be directly followed by the eye.

"(*a*) In the depth of the tissues there will be substituted for the spent lymph which has been extracted lymph freshly drawn from the blood-stream. This means that there will be substituted for a lymph which is favorable to the growth of all microbes indiscriminately a lymph which will stop the growth of *serosaprophytic bacteria and imperfect serophytes* (such as the gas gangrene bacillus); and at the same time seriously impede the growth of serophytic bacteria, above all, the growth of the streptococcus.

"Further, the microbes in the tissues, which, when immersed in the spent lymph were insusceptible, will, immersed in fresh lymph, become susceptible to phagocytosis.

"And in the induction of the phagocytosis in the interior of the tissues the imbibed salt will, we may take it, play a contributory rôle. For we have seen that salt, appropriately diluted, stimulates leukocytic emigration.

"(*b*) In the more superficial regions of the walls of the wound and adhering sloughs the hypertonic salt solution will break down the leukocytes and set free tryptic ferment—ferment which will, as we saw, not come into action so long as the concentration of the salt is maintained.

"The coagulation of the lymph on the face of the wound will also, as we saw, be inhibited by the hypertonic salt solution.

"(*c*) In the cavity of the wound microbic growth will at the outset be completely arrested by the hypertonic salt, and it will, after the lymph has begun to pour out, be inhibited to different degrees, according to circumstances by the combination of salt and antitryptic exudation.

"So long as the salt solution is maintained at full strength both emigration into and phagocytosis in the cavity of the wound will be inhibited.

"As soon as the hypertonic solution in the cavity has been sufficiently diluted by the outflowing lymph, the salt diffuses out from the infiltrated walls of the wound and the sloughs; and with this the tryptic ferment previously set free in these comes into action, and goes about its work of *cleansing digestion*—resolving the products of inflammation in the infiltrated tissues, and severing the connecting strands by which the sloughs are bound to the surface of the wound."

"At the same time—and this, be it noted, serves as a signal to the eye that the dilution of the salt solution has reached a point where all its inhibitory effects are abolished—leukocytes emigrate into the wound, and the discharge begins to assume a purulent character.

"Now also the bacteria begin to multiply in the cavity of the wound.

"We cannot afford to let all this go on very long unchecked. For as more and more trypsin finds its way into the exudate, or is set free in it from leukocytes disintegrated by microbic poisons, the effusion comes to furnish a more and more congenial nutrient medium for microbes, and the check imposed by phagocytosis is more and more completely removed. Finally, the exudate becomes tryptic, and if the

redressing of the wound is any longer delayed, ground will now be rapidly lost.

"It will have to be remembered, in connection with this description, that the conditions in every wound will be perpetually changing, and that these changes will not keep time in the different parts of a large wound."

This paper of Wright's is the most complete discussion of the subject, including exact description of the practical use of the different strengths of salt solutions in the treatment of infected wounds, and it is to be regretted that space does not permit of its complete reproduction. The paper concludes with the following practical suggestions:

"(1) Where blood continues to ooze from an operation stump or wound which has been packed with hypertonic salt solution, this will be due to this anticoagulative agent having been applied before the bleeding has stopped. The proper procedure will always be to postpone the use of hypertonic salt until all oozing of blood has ceased. Applied then, the salt will not resolve the blood-clot; and where the hypertonic solution applied is a 5 per cent. solution, a very little dilution will bring it to the point when blood clotting will no longer be inhibited.

"(2) When the face of the wound is found covered with a firmly adherent glutinous coating; this has been derived from leukocytes broken down by the direct application of strong salt.

"The way of avoiding this obstacle—it is, as a matter of fact, a serious obstacle to effective draining and irrigation—is to clean out all pus from the wound before bringing the hypertonic salt solution into application.

"(3) Where, as very rarely happens, the granulations become edematous, this will be due to the overprolonged application of concentrated salt solutions.

"It would seem that here the salt which is imbibed into the granulations is not sufficiently promptly carried off by the circulation, with the result that fluid is drawn into the salt-impregnated tissues, both from the underlying strata and also, when their salt contents diminishes, from the discharges.

"The remedy will be to discontinue the application of salt, and to apply hot fomentations in order to activate the circulation and promote absorption.

"(4) Where the granulations assume a bright coral red color and bleed at the least touch, it will be well to reduce the concentration of the salt solution—in the case where drainage of the tissues is still required to 2.5 per cent., and in the case where no further lymphagogic effect is required to 0.85 per cent.

"(5) Quite apart from the development of any undesirable secondary effects, it will be well, as soon as every trace of induration has disappeared and all sloughs have been got rid of, to substitute for the hypertonic a physiological salt solution.

"The rationale of this is that there will here still remain on the

face of the wound, even though it looks to the naked eye perfectly clean, serophytic microbes, which, though quite at home in the serum, can be killed by phagocytosis.

"In order to kill these—let us note that they are not killed but only inhibited in their growth by hypertonic salt solution—we must bring leukocytes to the surface of the wound."

Colonel Gray,[22] of the British Army, in describing infected war wounds outlines the application of the different strengths of salt solution and believes that they are productive of better results in general than any antiseptic solution.

Soap Solution.—Following the practice of certain French surgeons, Colonel Cuthbert Wallace suggested the trial of soap solution in the treatment of wounds in the British service, and Dixon[23] and Haycraft[24] published their experience with this agent.

Dixon used a $2\frac{1}{2}$ per cent. solution of yellow soap, which was found on analysis to contain: water, 24.6; fatty acids, 63.0; combined alkali, 4.6; free alkali, nil; impurities, 7.8. The wounds were dressed with sterile gauze soaked in the solution and the dressing was not changed for two, three, and four days, unless there was some evidence of infection. In some of the larger wounds he tried to apply the solution frequently through Carrel tubes, but it was too gelatinous to flow. He found that the wounds cleaned up quickly, that the dressing was much less painful, that there was a saving of labor, and that the solution was easily made and cheap.

Haycraft used the soap solution after débridement and closed a great many wounds primarily, and his results seemed to have been very satisfactory. Great stress, however, is laid upon the careful débridement.

Picric Acid.—Brown,[25] of the Australian Army, has used picric acid very extensively in the disinfection of wounds. He ascribes the following qualities to this agent: "(1) It kills bacteria without corroding effect and prevents suppuration; (2) it stimulates granulation of the tissue; (3) it has marked anodyne properties and the need of aspirin or morphia is rare: (4) by dispensing with hot fomentations it saves much time, cotton-wool lint, gutta-percha tissue, etc.; (5) it is less irritative and more efficacious than iodine; (6) it may be used for sterilization of the skin in surgical cases; (7) it shortens the convalescent period."

Conclusion in Regard to the Treatment of Infected Wounds.—It must be apparent from a perusal of the foregoing pages that many surgeons claim the same results from the use of widely different antiseptic solutions and from solutions which contain no germicidal quality whatever, but which instead seem to stimulate and aid the tissues in their natural combat against infection. But back of all successes lies the insistence that the first and most important point in the treatment is the thorough mechanical cleansing of the wound, "débridement," including not only the removal of all foreign material, but of all devitalized and contaminated tissue. And the success obtained, regardless of the agent subsequently employed, depends largely upon the care with

which the débridement is performed. From a rather unusual opportunity to observe the results of the various treatments outlined above, I am strongly of the opinion that no agent is so successful or has given such good results in the treatment of infected wounds as Dakin's solution employed according to the Carrel technic.

Drainage.—One of the striking changes in technic which the experience of military surgeons has strengthened is the elimination, as far as possible, of drainage of any kind in clean wounds. The elimination of drainage in clean wounds was very noticeable before the war, but certainly the experience and the practice of the method already described tended toward the complete abandonment of drainage in the absence of infection. There can be no doubt whatever that continued drainage is a potent cause of infection, and if for any reason one should employ a drain in a clean wound, it should be removed promptly within twenty-four or forty-eight hours and not replaced by another.

The partial closure of infected wounds with drainage, except in the case of the abdomen, should be abandoned and the wound should be left wide open, sterilized, and closed by secondary suture.

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CHAPTER XVI

FRACTURES*

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Pathologic Fractures.—The following classification of the causes of pathologic fractures is preferable to the one in Volume VI.

CAUSES OF PATHOLOGIC FRACTURES

1. Idiopathic osteopsathyrosis or fragilitas ossium.
2. Nutritional disturbances:
   (*a*) Rickets;
   (*b*) Osteomalacia;
   (*c*) Exhausting chronic diseases;
   (*d*) Senile atrophy;
   (*e*) Atrophy of non-use.
3. Inflammatory processes:
   (*a*) Osteomyelitis of diaphysis or epiphysis (epiphyseal separation in latter);
   (*b*) Tuberculosis and syphilis (rare).
4. Neuropathic conditions:
   (*a*) Tabes;
   (*b*) General paralysis of the insane;
   (*c*) Syringomyelia.
5. Neoplasms:

   Benign { Bone cysts (osteitis fibrosa),
   Enchondroma.

   Malignant { Carcinoma (secondary),
   Sarcoma (primary and secondary), including hypernephroma,
   Melanoma.

6. Echinococcus.
7. Osteo-aneurysms.

At the Cook County Hospital, Chicago, which receives a large number of fracture cases annually, we have found that tabes is the most common of all the above causes. Not infrequently the fracture is the first symptom; hence it is advisable to examine thoroughly the nervous system in every patient suffering from a fracture in which there is a minimum degree of pain upon manipulation at the seat of injury. The roentgenogram is often of little value in differentiating a tabetic from

* Supplementary to Chapter XXIV, Vol. II, p. 75, and Chapter XCIX, Vol. VI, p. 160.

a non-tabetic, *i. e.*, ordinary fracture. Of all of the other causes just enumerated, bone cysts and primary sarcomata are the most important to bear in mind. In a recent case a fracture of the upper end of the humerus followed a relatively slight injury. A roentgenogram taken upon admission revealed an extensive translucent area at the seat of fracture (Fig. 137), from which a diagnosis of a very early central sarcoma was made. This was confirmed by a second roentgenogram taken a few weeks later (Fig. 138).

Complications of Fractures.—Fat Embolism.—This complication has received considerable attention during recent years. The

Fig. 137.—Pathologic Fracture at Surgical Neck of Humerus Due to Central Sarcoma. The arrow points to line of fracture.

papers of Warthin,[1] LeCount and Gauss,[2] Ryerson,[3] and Caldwell and Huber[4] deal with the subject from the standpoint of the pathologist, the surgeon, and the experimental laboratory. There are two clinical pictures: one in which the respiratory, and the other in which the cerebral symptoms predominate. In the former, restlessness, dyspnea or other air-hunger, cyanosis, and vomiting are observed within a few hours to two days after a fracture or orthopedic operation. Râles appear in the chest, a blood-stained frothy mucus comes from the mouth, and there is fever which may reach 106° F. or higher. Fat appears in the sputum and urine. There is a rapid progressive course, with coma and fatal termination.

The cerebral form is characterized clinically by extreme restlessness, twitchings, convulsions, and paralysis. Some cases undoubtedly recover spontaneously, others are considered to be in a condition of delirium tremens, or to be suffering from embolism of a septic character. Rough manipulations should be avoided in recent fractures as well as in orthopedic cases. After the onset of symptoms of fat embolism the seat of fracture must be thoroughly immobilized and stimulants given.

FIG. 138.—SKIAGRAPH OF SAME CASE SHOWN IN FIG. 137 ABOUT FOUR WEEKS LATER.

Development of Tumors at Seat of Fracture.—We can find no authentic case report in which there was a direct relation between the fracture and the neoplasm. In every case thus far published the fracture either was a pathologic one—*i. e.*, a tumor was the cause of the solution in continuity—or there was only a history of injury and the tumor found at such a short interval afterward as to render it improbable that the injury has any casual relation.

Malunion and Non-union.—The most common causes of non-union in civil life are local and usually preventable. Syphilis has been

shown by experience to be not nearly so common a factor as was formerly believed. The following local causes must be considered:

1. Wide separation of fragments. This may be the result of insufficient reduction, or be due to primary destruction of a part of the diaphysis or an excessive removal of bone fragments.

2. Insufficient fixation.

3. Interposition of soft parts, usually muscle, less often tendons, periosteum, or fascia. This is one of the most frequent causes of non-union.

4. Severe protracted suppuration. This delays union, but does not cause non-union unless associated with necrosis of the ends of the bone.

5. The local action of foreign material used to accomplish internal fixation. Clinical observation and animal experiments have convinced many surgeons that in some cases foreign substances used to hold the fractured fragments in apposition, delay, and in some cases apparently prevent bony union from taking place.

The ends of the bone always show a distinct pathologic change in non-union, irrespective of the etiology, provided the non-union has lasted for some time. The usual finding is *sclerosis*, which may extend several centimeters from the ends of the fragments. These changes are due to the fact that the ends of the bone are deprived of the natural stimulus of contact and friction and their blood-supply diminished. Less often *atrophy* of the ends of the bone occurs (most commonly when there is a gap). The shaft then consists of a mere thin shell of bone filled with fatty marrow. In addition, the altered ends of the bone become surrounded by avascular connective tissue and this still further prevents union from occurring.

Treatment.—The treatment of non-union depends upon a proper knowledge of its etiology and pathology.

1. *Non-operative Treatment.*—It is often impossible to know whether or not union is merely delayed and will later occur; hence it is wise to wait a long time before resorting to operation. During this period it is important to stimulate osteogenesis by various methods. These are, in the order of their value: (*a*) movement, both active and passive. At first the movements must be painless and not tend to displace the fragments because of the danger of bending the soft callus. Active movement should be allowed as soon as it is not painful. Later, if non-union seems to be present and not merely delayed union, it is good practice and often of value to rub the ends of the bones together forcibly. (*b*) Deep massage. This is very valuable and should be used in all cases where it is not associated with pain. (*c*) Passive congestion. This is also of great value, and is most easily and satisfactorily carried out by the Bier technic, constricting proximally and at intervals with a Martin rubber bandage.

2. *Operative Treatment of Non- and Malunion.*—Various operative measures have been advocated to provoke the formation of callus, such as needling the ends of the bone, injecting blood or fibrin, or drilling the fragments. These seldom accomplish union where the non-opera-

tive methods fail. Before operating it is essential that the condition of the soft parts be rendered as favorable to success as possible.* In compound fractures where there has been infection at least three months should be allowed to elapse after the wound has completely healed, and even then operation should be done only in case the inflammatory process appears to have ceased. In order to make sure that no latent infection exists, *i. e.*, buried organisms without symptoms, it is advisable to employ forcible active and passive movements, elastic bands and massage, with the idea of obtaining a local inflammatory reaction if any be present, and in this case defer the operation still longer. During this period of waiting the functional condition of the muscles, joints, and nerves should be maintained by massage, electric stimulation, active and passive movements, in order to maintain the nutrition and prevent adhesions.

The incision in the skin should be placed so as to avoid any contact between the seat of fracture and the overlying wound in the skin. This is especially true of bones, such as the tibia, which lie in close relation to the skin. A constrictor should not be applied to the limb because a considerable amount of bleeding after its removal may jeopardize the success of the operation. All scars in the skin and soft tissues adjacent to the pseudarthrosis must be excised, because these diminish the blood-supply at the seat of operation. All interposing soft tissues should be removed, and finally, the ends of the bones must be freshened or the medullary cleaned out until the so-called "cap" of sclerotic bone has been removed and good healthy bone capable of osteogenesis exposed. Care should be taken to avoid injury to nerve trunks which are often enveloped by scar tissue. In parallel bones, such as those of the leg, an osteotomy of the less involved bone will prevent a recurrence of deformity.

The next question which arises is to choose a method of fixation. Those most commonly employed are:

1. Absorbable suture material. Kangaroo tendon has been employed by Albee more than any other surgeon with satisfactory end-results. It is especially applicable to bones like the clavicle, radius, and ulna, of both adults and children. Our own experience and that of many other surgeons is less favorable than that of Albee.

2. Metallic plates and bands, silver or bronze aluminum wire, ivory pegs and plates, screws, nails, or boiled ox-bone plates or pegs. The use of non-absorbable material for fixation of the bone fragments in cases of non- or malunion is not desirable. The Lane plates, although applied with the utmost precaution, favor infection, and union may be delayed or completely absent in many cases in which they are employed because the plates inhibit osteogenesis and prevent the end-to-end stress or frictional irritation, which, according to Roux, is so necessary for union. With the acquisition of familiarity with the technic

* During the Great War as all of the wounds were potentially infected with the germs of tetanus it was imperative to use a prophylactic injection of antitetanic serum. In civil life unless tetanus infection is suspected this may not be needful.

of bone-grafting we feel confident that the number of cases in which Lane plates and all other non-absorbable material is employed will constantly decrease.

3. The use of autogenous bone-grafts. This method bids fair to supplement all others, at least in civil life. The consensus of opinion is that all of the elements of the graft should be preserved. Although the retention of the periosteum is not essential to success, its absence means slower vascularization of the graft and a more prolonged convalescence for the patient. The graft is not a mere scaffold, but is really viable and carries its own powers of bone formation. The technic of bone-grafting and the essentials for success are so fully taken up in the special books on this subject that it is not necessary to repeat them here. There is no longer any difference of opinion as to the value of the autogenous graft, but the question as to whether the inlay, the sliding, or the intramedullary graft is the best is still debatable. One of the objections to the intramedullary graft for the shafts of long bones is that there is not sufficient fixation, and deformities, such as bowing at the seat of fracture, occur. In fractures of the neck of the femur this objection does not hold, and it has proved of great value in these cases. The inlay is preferable, as a rule, to the sliding graft unless the latter is made according to the method of Hoglund. The inlay graft is best taken from the antero-internal surface of the tibia, and not from its crest. The limb should receive support for five weeks after removal of the graft lest a fracture occur. Cases of this accident have been reported by Brooke, Dyas, and others. Altogether we believe that the use of autogenous bone-grafts will supplant all other fixation methods.

Operative Treatment of Closed (Simple) Fractures.—This is one of the most actively debated subjects in the entire field of fracture treatment. Some, like Lane and others in this country, believe that practically every fracture whose fragments cannot be brought into anatomically perfect apposition should be operated upon. Others, equally qualified to take part in the discussion, hold that very few if any closed fractures require operative interference. We believe that somewhere in the middle, between the radical and the ultraconservative viewpoints, there is a place for a rational, selective attitude which takes the following points into consideration before open reduction alone or combined with some method of internal fixation is decided upon. These points are:

1. The age and occupation of the patient, condition of the skin over the fracture, etc.
2. The interpretation of the skiagraph.
3. The experience and environment of the operator.
4. The results of efforts at closed reduction.

Let us take these up separately. 1. The age of the patient: The report of the committee of the American Surgical Association[5] found that conservative treatment was usually effectual below the age of fifteen and operative measures seldom if every indicated. This is in accord with the experience of the majority of surgeons. Speed[6] believes

that in aged persons who have senile changes, and are not in the laboring class, or are poor anesthetic risks, or would suffer from prolonged confinement in bed, the question of operation should be carefully considered. Again, if a patient's occupation is such that his living depends upon good use of the arm or leg, an attempt should be made to give the best function by operative reduction.

As to the condition of the skin, this may prove to be a contraindication when there are extensive abrasions or bullæ. This is especially frequent in fractures of the leg, so that operative interference must be postponed for weeks before the condition of the skin can be considered safe.

2. The interpretation of the skiagraph: We wish to plead for a calm judicial examination of the injured limb in conjunction with the skiagraph. Inspection, palpation, and measurements will very frequently reveal the fact that the skiagraphs give an exaggerated idea of the degree of displacement, and although exact anatomic replacement has not been obtained even with efforts at reduction under the fluoroscope, that there is no visible, palpable, or measureable deformity, and that the functional result will be as satisfactory as though an ideal end-to-end apposition had been obtained through operative measures. This is especially true of the humerus, tibia, and femur.

3. The experience and environments of the operator: There is very little if any danger from operative reduction of a closed fracture if the surroundings are those of a modern hospital; hence open reductions will be more and more employed in the future and the end-results of fractures be correspondingly improved. Such a procedure requires only an average degree of skill on the part of the operator. When the question arises, however, as to the application of a metal, ivory, or ox-bone plate, or the insertion of a bone transplant, the experience of the operator is the vital factor. Comparatively few surgeons, although they possess the necessary equipment, are gifted with the dexterity and knowledge of mechanics to plate a fracture or insert a bone-graft rapidly and accurately. This is the reason for so many bad results and much unjust condemnation of mechanical methods. If the surgeon has had ample experience with either bone plating or transplantation, we need no longer consider the employment of either of these now generally accepted methods of bone fixation as a contraindication *per se* to operation.

4. The results of efforts at closed reductions: Taking into consideration the preceding three sections, one is justified in either an open reduction alone or combined with some fixation method if all efforts at reduction compatible with a good functional result are of no avail.

Open Method of Reduction and Fixation.—Operative reduction alone will suffice in many cases if the fragments can be interlocked. If fixation is necessary, transplantation of bone is to be greatly preferred to any other method. If the Lane plate or the ox-bone plate (Fig. 139) are employed, the surgeon should test his armamentarium just before the operation in order to be able to work rapidly, which greatly lessens

Fig. 139.—Side View of Eeke Brougham Ox-bone Plate Employed for Temporary Bone Fixation in Ununited Compound Infected Fracture. (See Fig. 143.)

Fig. 140.—Fracture of Middle Third of Femur in a Girl of Twelve with Marked Displacement of Fragments.

On account of the inability to secure proper reduction a Parham band was applied. (See Figs. 141, 142.)

the chances of infection. A good bone-holding clamp and Lane bone elevators are of the greatest aid in plating. The use of a constrictor is inadvisable and unnecessary.

We prefer the ox-bone plate with screws of the same material to the Lane or Sherman vanadium steel plate. We have recently had the opportunity to observe the disadvantages of devices like the Parham band. In one of our cases in which another surgeon had applied the band around a fracture of the femur (Figs. 140, 141) we found that a

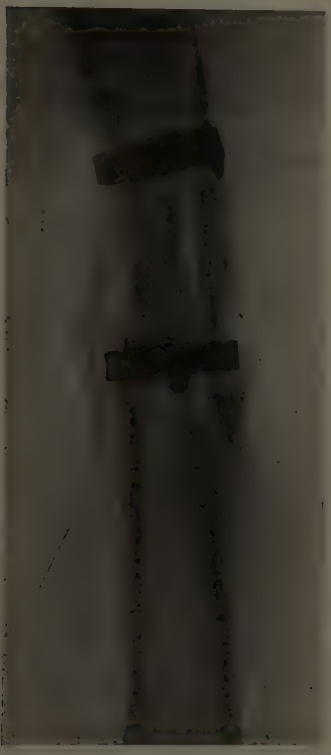

FIG. 141.—LATERAL VIEW OF FRACTURE OF FEMUR SHOWN IN FIG. 140 FOUR WEEKS AFTER APPLICATION OF PARHAM BAND.

FIG. 142.—VIEW OF FEMUR SHOWN IN FIGS. 140, 141. REFRACTURE AT LEVEL OF APPLICATION OF PARHAM BAND. NOTE HOW THE CALLUS FORMATION BOTH IN THE UPPER AND LOWER FRAGMENTS HAS BEEN INTERFERED WITH BY THE CONSTRICTING ACTION OF THE STEEL BAND.

refracture occurred (Fig. 142) owing to the constriction of the callus by the band. Andrews[7] has had two similar experiences. These 3 cases lead us to believe that advocates of this method of fixation should consider the possibility of such an accident. The advantages of the different forms of bone-grafts and their application is discussed in the section on Non-union. Kangaroo tendon may suffice in bones like the clavicle, radius, ulna, patella, and in tearing off of the tuberosity of the os calcis. Silver wire is seldom employed at present. As to the time of operation, we can see no advantage in waiting for four to

seven days, as advocated by some surgeons. We agree with Darrach[8] that immediate closed reduction of all fractures gives the best results, and the same is true of open reduction. Provided that the skin can be made safe for operation and the general condition is satisfactory, we can see no disadvantages in operating as soon as possible after the injury.

Compound Fractures in Civil Life.—Up to the time of the recent World War we recognized two forms of compound fractures in civil life. In the one the fragments simply punctured the skin and other adjacent soft tissues. In the other form there was a certain analogy in the injuries to the bone and soft parts to the explosive types sustained in war. This second form was most frequently the result of a direct crushing force with more or less extensive laceration and contusion not only of the overlying skin, muscles, and tendons, but in some instances of the nerves. The bone itself, instead of being broken in such a manner as to show an upper and lower fragment or possibly a number of large ones, would be so crushed as to convert the bone at the point of fracture into a mass of small fragments, many of which were completely detached. The first group where there was simple penetration of the surrounding soft tissues, al hough there was a possibility of infection having taken place, were, as a rule, treated conservatively by surgeons, with very satisfactory results in the majority of cases. In the second group—viz., the comminuted compound fractures—the results we have obtained in civil practice were very much like those of the early years of the recent war. Tetanus not infrequently followed such injuries even in civil life, and every effort was made to guard against such a complication by prophylactic injections of antitoxin within the first twenty-four hours. Gas bacillus infection, so frequent in the early years of the recent war, occurs often enough in civil life to be considered seriously. Infections with the ordinary pyogenic organisms, especially the streptococci, have not been so rare a complication of the compound fractures of civil life that we cannot profit by the experience derived especially during the last year of the war.

What are these war lessons, and how should they be applied to our compound fractures? We have learned that, no matter whether or not the injury was received in a soil teeming with organisms belonging to those which inhabit the alimentary canal of man and the lower animals, every compound fracture must be considered as an infected wound. According to Tuffier and others there is no appreciable growth of the organisms for from seven to thirteen hours after the injury, hence the infection remains so well localized and so superficial in the tissues that if the latter are resected for a depth of $\frac{1}{8}$ to $\frac{1}{4}$ inch during the first twelve to fifteen hours the freshened surfaces can be united and heal by first intention in 80 to 90 per cent. of the cases. This débridement or removal of the contaminated area applies especially to the soft tissues. As to the bone itself, the first problem is with the more or less detached fragments, and the second with the fixation of the

fracture. As to the former, the best method is to remove only the fragments which are completely detached, and to leave those with a periosteal bridge because each such fragment becomes a center for new bone formation. The freshening of the ends of the principal fragments should be carried out in the same manner as was done with the soft tissues, being guided by the great principle of conservation of as much bone tissue as possible. The second problem is concerned with the fixation of the fracture itself. There were many surgeons during the recent war who advocated the use of metallic plates, wire, etc., and maintained that this primary osteosynthesis did much to prevent non- and malunion. Other surgeons were violently opposed to such methods because of the delay in union which they caused. In the after-treatment, when infection had taken place either because the effort to

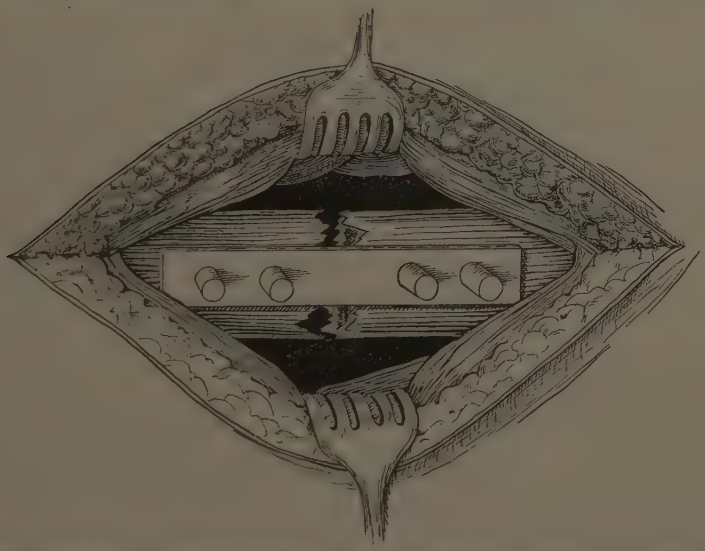

FIG. 143.—APPLICATION OF OX-BONE SPLINT TO UNUNITED COMPOUND INFECTED FRACTURE OF TIBIA. THE PLATE WAS REMOVED AS SOON AS UNION WAS FIRM. THIS CAN EASILY BE DONE BY UNSCREWING THE EXPOSED ENDS OF THE SCREWS. (See Fig. 139.)

obtain primary union had failed or the cases were received too late, another problem presented, viz., how to overcome the non-union which so frequently complicated these injuries. Secondary osteosynthesis with plates, etc., was employed with great success by many surgeons, combined with the Carrel-Dakin method, the seat of fracture being left exposed. After union had been obtained the plates, etc., were removed. Large granulating surfaces after being sterilized by the Carrel method were closed by secondary suture.

We believe that the treatment of compound fractures in civil life, both of the simple penetrating as well as of the more complicated varieties, can be vastly improved by the application of the principles underlying these war experiences.

It will seldom be necessary to do a primary suture with complete

closure of the wound. We can, however, excise all contaminated soft tissues, remove completely detached bone fragments, and resect conservatively the ends of the principal fragments. This can be followed by either a partial primary or primary delayed or even a secondary suture, procedures so clearly described in a recent article by Pool.[9] We must not overlook in this connection the tendency of organisms to persist in sequestra. The most dreaded form of infection in war fractures was the streptococcic, and this is true of those of civil life as well. We do not believe that the primary use of internal splints (osteosynthesis) is indicated in the compound fractures of civil life. If, however, infection has occurred, it can be controlled by the Carrel method, and at an early period a fixation of the fragments by the use of some such device as the Ecke-Brougham ox-bone plate will be of great benefit. We have had occasion to employ these in two very severely infected compound fractures recently, the plates being left exposed (Fig. 143) and a fenestrated cast applied. As soon as union was firm the plates were removed, and the results obtained amply justified the use of such a temporary fixation method. In one case a large granulating surface, following extensive undermining of the skin by the infection, was closed (after being rendered sterile) by secondary suture. The use of the Willems method of early mobilization of joints has proved of the greatest value in the treatment of infected compound fractures extending into major joints.

Joint Fractures.—The three most important additions to our knowledge of the treatment of intra-articular fractures are:

1. The more general employment of the acute flexion position in fractures of the elbow (except those of the olecranon).
2. The early mobilization of injured joints as suggested by Willems.
3. The application to civil life of the lesson learned during the recent war in regard to the treatment of open joint injuries.

All of the recent contributors to the subject report a very large percentage of perfect results following the use of the acute flexion position. Neuhof and Wolf think that their 100 per cent. of perfect results in 100 consecutive cases of fractures of the elbow of all types in both adults and children are due to the fact that mobilization of the joint was begun four to five days after the injury. Ladd has found that this increases the amount of callus and that the ultimate degree of motion is limited by the use of early massage and motion. Neuhof denies that either of these occurs, and also that there is no danger of displacement of fragments. Mayet deviates somewhat by placing the arm in extension for ten days and then changing to the position of acute flexion. We can see no reason for this, and can warmly recommend the Jones position of acute flexion, which has been so ably called to the attention of American surgeons through the publication of Ashhurst. We prefer after reduction under anesthesia to apply a molded plaster splint, similar to that employed in Colles' fracture, the forearm being flexed upon the arm in the most acute angle possible, the average being 20 to 35 degrees. Any position short of this, as Ashhurst and Neuhof

point out, does not abolish the lever action of the forearm, which tends to cause a recurrence of the displacement. In cases where operation is necessary, the best results are obtained from doing so as soon as possible after the injury (see section on Operative Treatment). In such flexed positions at joints if skin is in actual contact with skin ulceration will soon occur. Some cotton should always be interposed between the two cutaneous surfaces to prevent this unfortunate result. Reduction of fractures of the external condyle is more frequently necessary than any other portion of the humerus. From our own experience we can heartily endorse the recommendation of Neuhof to immobilize the joint for the briefest possible time.

2. Early mobilization of injured joints. Willems in 1909 first reported a method of immediate mobilization of injured joints, whether infected or not. The reports of many surgeons who have had an opportunity to apply the method during the recent war are nearly unanimous in their endorsement of the value of such early mobilization. In recent publications Willems[10],[11] describes his method in detail and emphasizes the necessity of beginning active movements immediately after the injury, and not to wait for hours to days. Pain is rare after this early mobilization, and there is no danger of displacement of fragments. We have had occasion to employ this method in the infected compound fractures of civil life, and believe that it is well worthy of careful study.

3. The treatment of open injuries of the joints has been completely revolutionized by the experience of surgeons during the last year of the war. We believe that many of the lessons learned through the use of primary, partial primary, primary delayed, and secondary suture of injured joints with fracture of the articular ends can be applied to the same injuries in civil life. If the percentage of successful results after thorough débridement of an open fracture has been so high under less favorable conditions, we can see no reason why equally good if not better results cannot be secured when the surgeon has at his disposal the more ideal conditions of civil practice.

Sprain Fractures.—Ross and Stewart[12] found this condition in 15 per cent. of 145 cases studied by them. The diagnosis is based upon the history of a force sufficient to cause a fracture and the local findings: (*a*) a point of tenderness at the point of attachment of a ligament or tendon, (*b*) swelling over this area unless obscured by a swelling of the entire joint, (*c*) the skiagram if taken in the proper place shows a tearing off of all or part of the bony attachment of the respective ligament or tendon. The skiagraph is the most reliable method of diagnosis. Overlooked cases suffer from chronic arthritis, persistent tenderness, and weakness in the use of the joint; excessive callus formation is not an uncommon finding in such old cases. Immobilization for three weeks is the only treatment for recent cases.

Epiphyseal Separations.—MacAusland collected all of the cases of separation of the lower femoral epiphysis published up to 1916, and believes that open reduction is the best method of treatment.

In 18 of Montgomery's cases the injury was received by being caught in a revolving wheel or machinery, while in 7 it was the result of a fall or of a direct injury. Amputation had been done in 14 of the 27 because of the damage sustained at the time of injury. In 5 of these it was performed because of hemorrhage, infection, or an aneurysm developing in the popliteal space. Resection has been done where the proper alinement could not be secured. Open reduction at an early period is the operation of choice, and resection should be resorted to only when the deformity and disability resulting from failure to reduce the displacement would be greater than that resulting from shortening of the extremity.

Elmslie[14] has called attention to the fact that a fracture through the lower epiphysis of the tibia causes an arrest in the growth of the bone. The scar diminishes the ingrowth of vascular loops which furnish osteoblasts. In one of his cases such an injury was followed by a varus deformity.

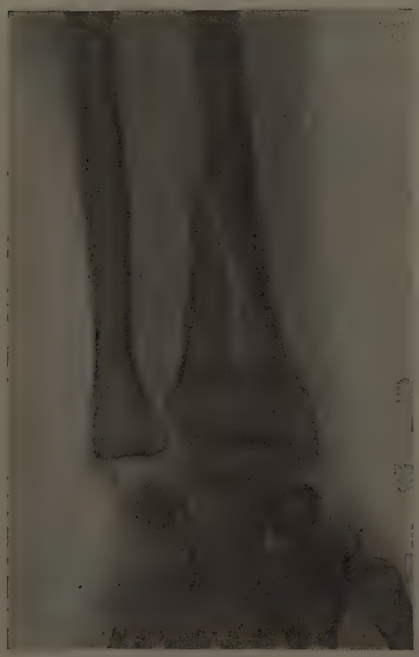

FIG. 144.—LONGITUDINAL FRACTURE OF LOWER END OF RADIUS.

Fractures of the Neck of the Scapula.—Hitzrot and Bolling have collected all published cases and report 8 of their own. The cases fall into three groups: (1) Fractures of the surgical neck, (2) those of the lower half of the neck, (3) those beginning at the notch and extending downward through the base of the coracoid process to the glenoid fossa. In the first and second groups the fracture followed a fall upon the shoulder. There was no characteristic deformity in 5 of the cases belonging to the first group and in 1 of the 2 cases of the second group. In one of the latter there was a marked flattening of the shoulder due to a coincident circumflex nerve injury. Disability was complete in all 7 cases. Pain was present over the coracoid process. The diagnosis can be made with certainty only by roentgenographic examination. The only treatment is immobilization for three to four weeks, followed by active and passive movements.

Fractures of the Lower End of the Radius and Ulna.—Pilcher[16] believes that two chief forms of fracture are found according to the forces of cleavage. In one there is a perpendicular wedge-like impact of the carpus against the articular cup of the base of the radius, resulting in a longitudinal fracture (Fig. 144), which is rare compared to the

second variety. In the latter a splitting of the lower fragment takes place as the result of the descent into it of the lower end of the upper

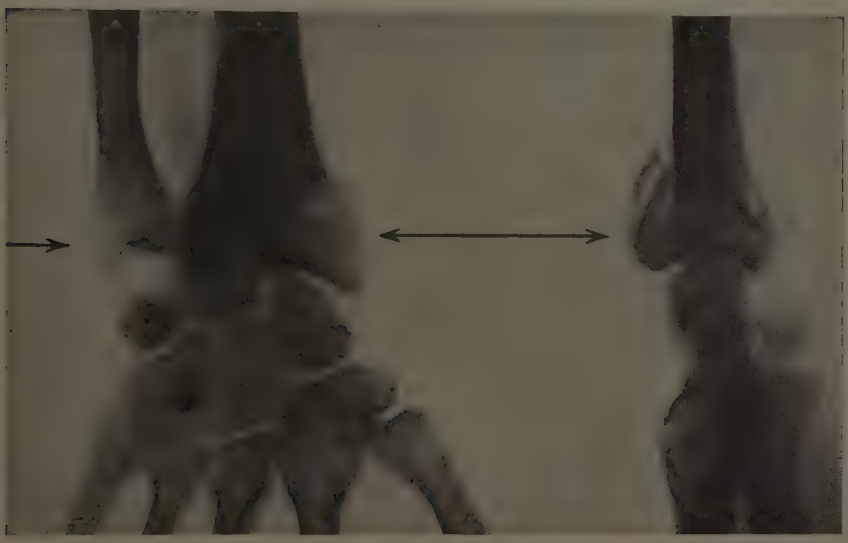

FIG. 145.—ANTEROPOSTERIOR AND LATERAL VIEWS OF TYPICAL IMPACTED FRACTURE OF LOWER END OF RADIUS AND ULNA.

Note also fracture of styloid process of ulna to which single-headed arrow points.

FIG. 146.—REDUCTION OF IMPACTED COLLES' FRACTURE.

One hand grasps the patient's hand while the other grasps the forearm just above the point of fracture. By a rocking motion and alternate flexion and extension (Fig. 147) the impaction can be readily broken up.

fragment. The degree of the entanglement is a fair index of the force which the elements of the wrist have had to sustain. The lower fragment may be comminuted by the upper one. In the majority of cases

FIG. 147.—REDUCTION OF IMPACTED COLLES' FRACTURE.

After flexing the hand upon the forearm forcibly as shown in Fig. 146 the hand is hyperextended. If this does not suffice to break up the impaction it may be necessary to add the movements of adduction and abduction.

FIG. 148.—REDUCTION OF IMPACTED COLLES' FRACTURE.

The position of the hand and forearm before application of molded plaster splint. Note the flexion of the wrist and also the ulnar flexion (abduction).

there is really not a true impaction, but rather an entanglement of the serrated surfaces of the one fragment into the irregularities of the

other. We believe that this entanglement is the chief obstacle to perfect reduction. It is the failure to appreciate this entanglement

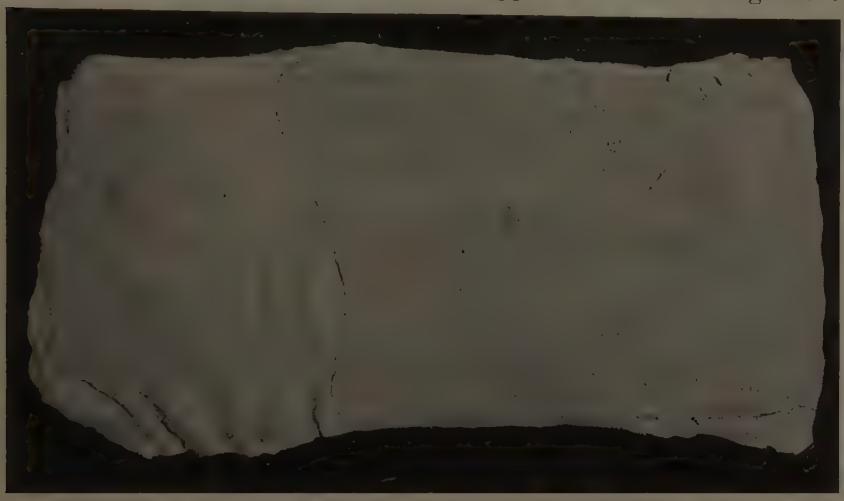

FIG. 149.—REDUCTION OF IMPACTED COLLES' FRACTURE.

Plaster splint made by rolling a 3-inch plaster-of-Paris bandage back and forth before being applied to hand and forearm in treatment of Colles' fracture. The distance is measured from a point corresponding to the middle of the dorsum of the hand to a point far enough below the elbow to permit flexion of this joint. This represents the length of the splint. The lower fragment is thus brought into line with the upper, preventing displacement of the lower fragment toward the radial side of the wrist.

FIG. 150.—REDUCTION OF IMPACTED COLLES' FRACTURE.

Molded plaster splint applied to hand and forearm. Note flexion of hand upon forearm and abduction (ulnar flexion).

(Fig. 145) which is responsible for so many poor results after fractures at the lower end of the radius, because it must be broken up before attempts at alinement of fragments are made.

Longitudinal (Fig. 144), transverse (chauffeur's), and other forms of fracture may occur without such impaction and require less correction of displacement of fragments. Simple immobilization for three weeks with the fingers free suffices. Complete relaxation under general anesthesia followed by manipulation to break up (Figs. 146–150) the entanglement or impaction of fragments is the keynote of success in 80 to 90 per cent. of Colles' fractures. We have secured the most satisfactory results in these cases by flexing and abducting the wrist, placing the hand in position, and then applying a molded plaster splint. The patient is encouraged to use the fingers constantly, and the molded plaster splint is removed at the end of the fourth week. Active and passive movements are then begun, but the splint is reapplied daily until the end of the sixth week on account of the tendency of the soft callus to yield and displacement of the lower fragment toward the distal side to occur.

Fractures and Dislocations of the Carpal Bones.—Many cases formerly treated as sprains of the wrist followed by a considerable limitation of motion and persistent pain were undoubtedly overlooked fractures or dislocations of these bones. In the monograph by Hirsch[17] all of the literature to 1914 has been thoroughly reviewed.

Frequency of Individual Injuries.—The most frequent injuries are: (*a*) fracture of the scaphoid bone (os naviculare), (*b*) dislocation of the semilunar bone (os lunatum), and (*c*) combinations of (*a*) and (*b*). That fractures of the other carpal bones occur is not to be denied, but they occur with comparative rarity. The only recent statistics available are those of Marshall[18] and McCarty.[19] The former reported 81 cases from the Massachusetts General Hospital, of which 64 were fractures of the scaphoid.

McCarty in a study of 118 cases found that 108 were fractures of the scaphoid, 5 had dislocations of the semilunar bone, 2 fractures of the pisiform, 1 of the os magnum (os capitatum), 1 of the unciform (os hamatum), and 1 of the cuneiform (os triquetrum).

Hirsch collected 38 cases of fracture of the semilunar, and is of the opinion that fracture of this bone occurs more frequently than that of any other of the carpal bones except the scaphoid. He was able to find only a few reports of fractures or dislocations of the other carpal bones.

Fracture of the Scaphoid.*—As a rule this occurs by indirect, less often by direct, violence, *e. g.*, while cranking an automobile. In the former there is always a history of a fall upon the palm of the hyperextended hand (Fig. 151), while the latter is deviated toward the ulnar side.

There are two forms of fracture of the scaphoid: (*a*) of the body and (*b*) of the tuberosity. The former occurs through the middle of the

* Although a congenital division of the scaphoid has been found in postmortem specimens, no actual cases have ever been demonstrated by *x*-ray or at operation. The absence of a history of injury and of the usual findings of scaphoid fracture would enable the experienced surgeon to exclude such an anomaly.

articular surface (Fig. 152). The line of fracture may be smooth or ragged. Fractures of the tuberosity (Fig. 153) occur less often than those of the body, the tuberosity being either torn off as a whole or split into several fragments.

There are three chief mechanisms involved in fractures of the scaphoid: 1. Tearing. This always involves the tuberosity and follows dorsal combined with ulnar flexion, causing a tearing off of the ligament binding the styloid process of the radius to the tuberosity of the scaphoid.

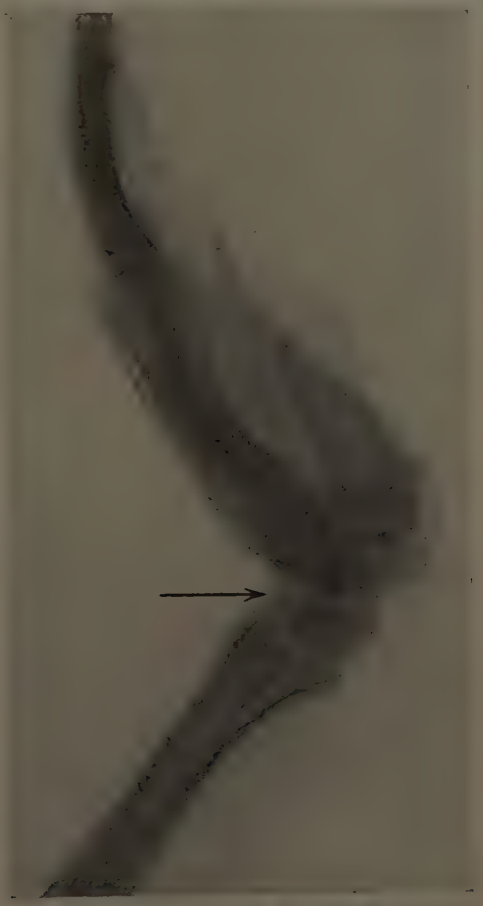

FIG. 151.—HYPEREXTENDED NORMAL ADULT HAND SHOWING HOW SCAPHOID IS CRUSHED. (See text.) ARROW POINTS TO SCAPHOID.

2. Compression. Here hyperextension of the wrist (dorsal flexion) is associated with radial flexion (adduction). The former fixes the carpal bones so that the scaphoid cannot escape, and it is crushed between the radius and the os magnum.

3. Flexion mechanism. This can act in both ulnar flexion (abduction) and radial flexion (adduction), combined with hyperextension of the hand (dorsiflexion). In the first named the radius compresses the

scaphoid until it yields on its convex side. In combined ulnar and dorsal flexion the bone breaks on its concave surface just as when a stick is broken across the knee. This is due to the fact that the bone

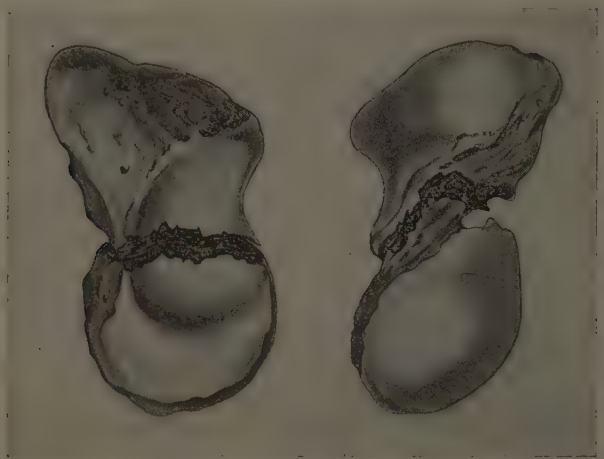

Fig. 152.—Two Views of Fracture of the Scaphoid Through Middle of the Body.

is fixed by ligaments both proximally and distally and is broken across its bony support (os magnum) on its concave side.

The most valuable symptom of scaphoid fracture is severe pain, especially on pressure over the tabatière.* The next most important

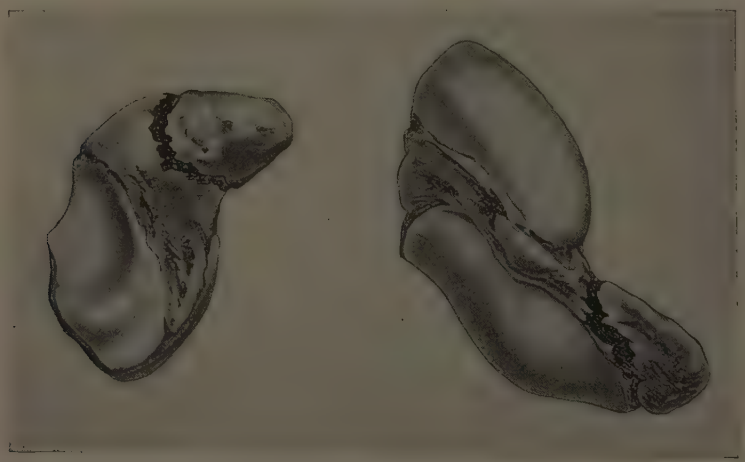

Fig. 153.—Two Views of Fracture of Tuberosity of Scaphoid.

sign is swelling of the wrist-joint with effacement of the depression, known as the tabatière. The third symptom is limitation of motion, especially in the direction of extension or adduction (radial flexion) of the wrist.

* Tabatière, or Frenchman's "snuff-box," is the depression on the back of the abducted thumb between the extensor tendons of the thumb.

A roentgenogram with the hand in extreme ulnar flexion (abduction) so as to bring the scaphoid away from the radial articular surface is the best. Stereoscopic views in both the above anteroposterior and in the lateral directions (Fig. 145) are the most satisfactory. Lateral views show fractures of the tuberosity best.

Treatment.—Fractures of the tuberosity heal rapidly and do not require immobilization. Those of the body should be treated conservatively, especially if there is no displacement of fragments. Even if the latter condition exists, attempts to reduce the displaced fragment should be made by manipulation. Many wrists regain good function after three or four weeks' immobilization followed by gradual resumption of active and passive movements until pain subsides. Operative interference is indicated only after a long interval has elapsed and it has become likely that disability from chronic irritation will be lengthened by further delay. In these old cases with non-union or displacement of the fragments operation is indicated if the soreness persists for a long period or recurs frequently enough to cause serious disability. Hirsch is even more radical than Marshall and all others. He believes that conservatism rarely leads to a good functional result and advocates primary removal of all fragments.

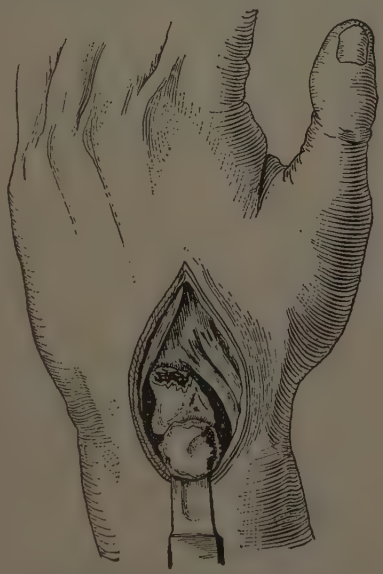

Fig. 154.—Fracture of Scaphoid. View of dorsum of wrist showing removal of fragments of scaphoid. (After Hirsch).

The best incision for removal of the fragments is one over the dorsum of the wrist (Fig. 154). The gap following removal of the fragments becomes filled by fibrous tissue. Perfect restorations of wrist motions after operations appear to be rare (Marshall), but fairly serviceable wrists ultimately should be expected.

Dislocation of the Semilunar Bone.—In the first stage there is a forward or volar displacement, and in the second the bone undergoes a rotation of 90 degrees, so that its radial articular surface looks toward the palm of the hand. This injury, like fracture of the scaphoid, follows a fall upon the hyperextended hand; rarely it occurs as the result of direct violence (cranking an automobile). The mechanism resembles one of those (flexion) described under Fracture of the Scaphoid. In reality, the injury results in a dorsal dislocation of all the carpal bones with the exception of the semilunar, which remains in its normal position.

Symptoms.—In recent cases one finds only a diffuse swelling of the wrist, but in older cases (after a month) a deformity is present depending as to its character upon whether the dislocation ended in the first

or second stage; if the former, we have a silver-fork deformity, like that of a Colles fracture, but more distally located and sharper. In the second stage there is a distinct prominence over the front of the wrist (Fig. 155). Flexion of the wrist is impossible, and pain due to pressure on the median nerve is present.

A lateral roentgenogram is the most satisfactory, especially a stereoscopic one. The semilunar is seen not to articulate with the os magnum, and if rotation of the semilunar has taken place, its articular surface looks toward the palm of the hand or even proximally toward the forearm if it has rotated 180 degrees.

The *prognosis* is bad because of the inability to bend the fingers and also because of nerve disturbances associated with atrophy of the hand and forearm muscles.

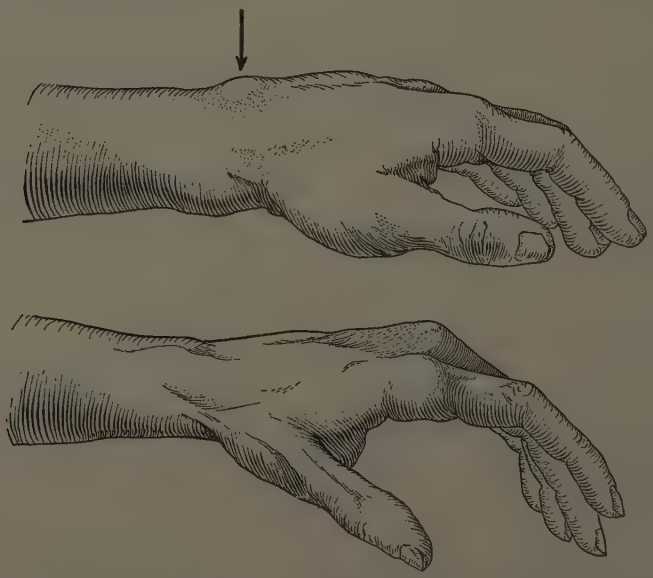

FIG. 155.—DISLOCATION OF SEMILUNAR BONE.

Lower picture shows lateral view of normal hand. Upper picture shows prominence due to dislocation of all the carpal bones except the semilunar, the prominence due to dislocation of latter being shown in front of wrist. (After Hirsch.)

Treatment.—Closed reduction should be attempted in recent cases, especially in those without rotation of the bone. If this is unsuccessful, it is best to remove the displaced semilunar bone through an incision over the front of the wrist (Figs. 156, 157). Care should be taken not to open the flexor tendon sheaths. One needs only to divide the attachment of the semilunar to the radius to remove it. Active motion can be begun after the first week.

Of 85 cases of removal of the semilunar collected by Hirsch, 38 have given very successful results. The earlier the bone is removed, the better the functional result.

Injuries of Other Carpal Bones.—Of these, fracture of the semilunar bone takes first place as to frequency. It occurs during ulnar

FIG. 156.—DISLOCATION OF SEMILUNAR BONE.
Incision over front of wrist for removal of semilunar bone. (After Hirsch).

FIG. 157.—VIEW OF FRONT OF WRIST SHOWING METHOD OF REMOVAL OF DISLOCATED SEMILUNAR BONE. (After Hirsch).

flexion of the hyperextended wrist and is a compression injury similar to one of the mechanisms in scaphoid fracture. The diagnosis can be

made only by roentgenographic examination. It should be treated by applying extension in the line of the metacarpal bone of the middle finger.

Only a few reports of fractures or dislocations of the other carpal bones have been published.

Fractures of the Sesamoid Bones of the Hand and Foot.—The constantly present sesamoids of the thumb are found on either side of the metacarpophalangeal joint. Four cases of fracture of these have been collected by Skillern, including one of his own. He was also able to find a normal skiagram showing the presence of sesamoids on all of the remaining fingers, a condition which is very inconstant. Fractures of the sesamoids of the big toe occur more frequently than do similar injuries in the thumb. Müller up to 1912 collected 16 cases, including one of his own. The external or fibular sesamoid was involved in 1, the tibial in 9, and in 5 a division was found in both feet. That such a congenital division exists in both sesamoids of the thumb and big toe has been recognized for some time, so that some of the cases in Müller's series must be excluded for this reason. Boardman has recently reported 5 cases of this congenital division in the sesamoids of the big toe. It occurred most frequently in the tibial sesamoid. Skillern and Boardman both call attention to the fact that such a congenital division can be distinguished from a fracture by the smoothly rounded and regular shape of the two fragments in a con enital division, while in a fracture the edges are irregular and dentated. Orr collected 24 cases of fracture of the great toe sesamoids published up to 1918. Fractures of the sesamoids of the thumb are usually due to indirect violence, while those of the toe may be due to either a sudden fall upon the feet (indirect) or a heavy weight dropping upon the toe (direct). The latter is the more frequent mode of injury. The symptoms are due to a low-grade inflammation of the adjacent joint with which the seasmoids are in most intimate relation. At the time of injury there is usually a sudden sharp pain in the big toe. The treatment is immobilization, but operative removal of the fragments may become necessary in obstinate cases.

Fractures of the Neck of the Femur.—The two chief causes of unsatisfactory results in the past have been, first, the loss of the normal angle which the neck makes with the shaft, and second, non-union. All of the recent methods aim at the correction of these two causes in the following ways:

1. The Whitman method fixes the limb in complete abduction, slight extension and inward rotation. In non-impacted cases the displacement is upward, backward, and outward. By pulling the limb downward to its normal length, lifting it forward and rotating inward, the fragments are apposed in a lateral direction. In order to re-establish, however, the normal angle of the neck with the shaft it is necessary to also abduct the limb, which through the tension exerted upon the capsule brings the fragments into alinement because the head is fixed in the acetabulum. A long plaster spica (Fig. 158) is applied and retained as a support for eight to twelve weeks. In impacted fractures

deformity which interferes with function should be corrected even if resistant. This breaking up of the impaction (which, as in the case of Colles' fracture, is, in reality, only an entanglement of the fragments) does not endanger union, but assures it through more accurate adjustment of the fractured surfaces.

2. The method of artificial impaction was first suggested by Cotton and is employed by him in *a*) intracapsular cases without impaction; (*b*) all cases in which adduction and eversion (especially the latter) are extreme; and (*c*) all cases in which the impaction gives way. Cotton aims to place these cases in the more fortunate class of impacted fractures.

FIG. 158.—METHOD OF APPLICATION OF THE WHITMAN CAST FOR FRACTURE OF THE NECK OF THE FEMUR. (Courtesy of Dr. Royal Whitman.)

3. Open reduction and use of bone-graft. Albee believes that this method is indicated in all ununited fractures and in most unimpacted cases if there are no contraindications so far as age, etc., are concerned.

4. The transplantation of the head to the great trochanter in old united cases. Brackett employs this method when the entire neck has been absorbed. The head is placed on the inner side of the sawed-off trochanter so that the weight bearing is along the normal lines.

Our personal experience has been chiefly with the Whitman method, and the results have been so satisfactory that we can warmly recommend its adoption in all recent cases with or without impaction. In the latter group we have adopted the disentanglement of the fragments

under anesthesia as a more or less routine procedure and then proceeded to apply the plaster spica (Fig. 158).

Fractures of the Patella.—The early operative treatment of this injury has almost supplanted the non-operative. The end-results of the former are clearly shown to be far superior. Scudder was able to re-examine 38 cases which had been operated upon; 94 per cent. had full extension, and 60 per cent. full flexion; 57 per cent. had both of these movements. Of 22 which were roentgenographed, 81 per cent. showed bony union, 18 per cent. had a bony bridge between the fragments, while 18 per cent. had no bony union, but even in these there was good function.

Motion, both active and passive, should be begun as early as the end of the second week. Absorbable material, such as chromic catgut or kangaroo tendon, is now most universally employed. Great care should be taken to approximate the torn edges of the aponeurosis; if possible, by the imbrication method employed in umbilical hernia. If the periosteo-aponeurotic covering of the bone itself is firmly sutured it is not necessary, as a rule, either to penetrate the bone itself or to encircle the bone with a suture. The broken edges of the patella can be closely approximated without any difficulty. Albee has employed his inlay method in both recent and old ununited fractures. The bone-graft is of the greatest advantage where there has been a fibrous union in an old case and a separation of the fragments coincident with a shortening of the quadriceps tendon and muscle. A long graft will entirely or to a large degree fill in the space between the fragments. Brickner operated an old case with side separation of fragments by an ingenious free muscle-tendon-bone transplantation with excellent results. Phemister has employed a similar method, using a free transplant of the fascia lata.

Fractures of the Tibia and Fibula.—In the section on this subject in Volume V we recommended the employment of the blanket splint or the fracture-box as temporary dressings until the swelling subsided sufficiently to permit a proper reduction of the fragments to be made and a cast to be applied. We have had ample opportunity during the interval since the above recommendation was made to see the dangers and disadvantages of such a procedure. We strongly urge at the present time the immediate reduction of all fractures both simple and compound, especially those of one or both bones of the leg, as soon as the necessary skiagraphs have been taken. We still use the blanket splint or some other mode of fixation as a transport or temporary splint until the necessary skiagrams have been made. If the local environment is such that there are no facilities for taking skiagrams, we believe even under such circumstances that the fracture can receive better attention through immediate reduction and cast than any other method. If the injured man is in a hospital and the skiagrams have been made and examined, we immediately anesthetize him and proceed by traction and manipulation to reduce the fracture and apply a circular cast extending from the toes to the middle of the thigh. Every modern hospital should possess

a Hawley or similar fracture table, because it greatly simplifies the reduction of such a fracture and its fixation during the application of a cast. In cases with but little swelling of the soft parts a strip 1 or 2 inches wide and of the whole thickness of the cast is removed for the entire length of the front of the cast. If there is much swelling an extra number of layers of sheet wadding are placed around the limb and the entire anterior half of the cast removed, leaving practically a posterior plaster molded splint. The skin has, of course, been given the necessary attention before the cast is applied. The disadvantages of late reduction are self-evident, and the danger of decubital necrosis from a displaced fragment, especially in the vicinity of the ankle or at the heel, is familiar to those of us who have watched these cases for seven to ten days while they are being treated in a fracture-box. There is absolutely no contraindication to immediate reduction and a plaster cast will keep the fragment more perfectly fixed than any form of splint, at least in civil life. The portion of the cast removed (as described above) will allow for all possible increase of swelling and access to the injured skin, if necessary. If the skiagrams taken after attempts at reduction have been made show that operative measures are indicated, the temporary cast can be readily removed.

Fractures of the Os Calcis.—The articles by Cotton,[27] Henderson, Lounsbury,[28] Cahill,[29] and Magnuson[30] cover the subject very thoroughly. Simple fissured fractures without displacement require only a cast for four weeks. Those with much upward and backward displacement of the posterior fragment Lounsbury treats by strong downward traction with the aid of an ordinary urethral sound passed in front of the tendo achillis, while strong upward pressure is made on the anterior fragment in the sole of the foot. According to Magnuson, fragments are best held in position by severing the Achilles tendon and then applying a cast as far up as the knee. The patient should not be allowed to place any weight on the foot for ten weeks, and then only after using arch supports, preferably a felt pad rather than a metal plate. In tear fractures at the point of insertion of the tendo achillis it is best to suture the tendon to the bone. In comminuted fractures with displacement the results are not satisfactory because of the flattening of the longitudinal arch. According to Brind,[31] he examined a large number of cases six months after the injury and found that the majority showed only a decrease of 25 to 30 per cent. of their working capacity. At the end of a year this had been lowered to 15 to 20 per cent.

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CHAPTER XVII

GUNSHOT FRACTURES

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PECULIARITIES AND VARIETIES OF GUNSHOT FRACTURES

Besides being always compound, gunshot fractures differ from ordinary fractures in that they are produced by the direct action of bodies striking, piercing, or carrying away portions of the bones, and in that the bending and twisting stresses and strains, the usual factors causing the latter, are generally absent or subordinate.

The importance of this fact in relation to the processes of repair is not always appreciated. The ordinary compound fracture is usually compounded from within, that is, by the protrusion of the fragments through the skin; while the gunshot fracture is compounded from without, and is consequently more likely to be contaminated by the entrance of foreign material.

On the other hand, in the case of the ordinary fracture the fragments are more frequently stripped off the soft parts covering them and, consequently, suffer more from lack of nutrition. Even when missiles produce extensive comminution the majority of the fragments retain their connection with the soft parts and reproduce bone rapidly, unless their vitality is further impaired by infection. Repair is so rapid in non-infected comminuted gunshot fractures as frequently to produce definite consolidation in periods which would be very remarkable in the case of ordinary fractures; such as, for instance, sixteen to eighteen days for the humerus and thirty to thirty-five days for the femur. In gunshot fractures without comminution the period for repair does not differ materially from that for the ordinary fracture by indirect violence, except in that there is less likelihood of interposition of the soft parts and the non-union caused thereby. On the other hand, gunshot fractures may be produced not only by the impact of the missile, but by other stresses and strains to which the bone is subjected at the moment, consequently gunshot fractures may possess the same characteristics as the ordinary fracture. Occasionally double fractures occur, one being caused by the action of the projectile alone, the other probably by the violent vibration set up by the projectile plus some other torsional or bending strain. The second is usually some distance from the first and is a simple fracture.

Every conceivable anatomic variety of fracture may be produced by missiles, varying from a slight chipping of the surface to extensive com-

minution or splintering. The fissures may extend the entire length of the shaft and into the articulation, a feature of great importance both as regards prognosis and treatment. However, the presence of hemarthrosis, such as of the knee accompanying gunshot fractures of the femur, does not necessarily imply extension of the fracture into the joint, as it is quite common even in transverse fractures as high as or higher than the middle of the femur.

Wounds of the bones which do not produce complete solution of continuity of the shaft are usually termed as such, the word "fracture" being reserved for the complete lesions. Sometimes the term "partial fracture" is employed, but is somewhat ambiguous. In the case of the epiphysis the term "fracture" is commonly applied to all wounds, but should be reserved for those in which the lesion amounts to separation of so important a fragment as to produce deformity or mechanical interference with function. On account of the softness and elasticity of epiphyseal bone there is little tendency to fissuration as compared with the diaphyses, and there may be extensive wounds without implication of the articulation. For the same reasons, there being less resistance to the projectile, the latter is not so often deformed, and consequently does not cause as much damage as it otherwise might. Small wounds of the epiphyses are often difficult to detect, for the elastic outer shell of the bone snaps back, completely closing the point of entrance. Yet the injury is rarely confined to the actual path of the projectile through the cancellous tissue. Usually a diffuse hemorrhagic area surrounds its path, or there may be scattered hemorrhages at a distance from it. These, in the case of infection, may become necrotic, and as they do not communicate directly with the wound, form dangerous abscesses or at least prolong infection.

The most important features of gunshot fractures as contrasted with civil fractures are (1) the traumatism of the soft parts and (2) the entrance and lodgment of foreign material, chiefly projectiles and clothing, the latter being carried in by the former.

The injury to the soft parts may be very slight when caused by a rifle ball traveling at moderate velocity, or it may be terrific when the ball is traveling at high velocity. In the former case, although the ball may have had sufficient momentum to break the bone and pass completely through the limb, the wounds in the skin may be surprisingly small and punctate in character, and the injury to the muscles negligible.

Such wounds almost invariably close by themselves and the fracture is, to all intents and purposes, a simple fracture.

On the other hand, the rifle ball at high velocities is usually highly destructive to both bone and soft parts. Possessing a tremendous energy in foot pounds, its destructive effect depends upon whether this energy is absorbed by the tissues or not. For example, a rifle ball at high velocity may pass with great ease through the soft parts, little of its energy being lost and little damage done. On the other hand, if its energy is absorbed by the bone, not only is the bone shattered into many fragments, but these fragments, having acquired some of the energy of

the missile, act like a miniature bursting shrapnel and tear the soft parts to shreds. In such a case there may or may not be sufficient energy remaining to the missile to effect its passage through the limb. Usually having been disrupted by the force of its impact on the bone, part of it may pass through the limb and part, usually the jacket, remain lodged. Frequently the lead spatters into innumerable flat scales, highly evident by radiography, but impossible to find at operation.

When a deformed ball or portions of a ball pass entirely through the limb the wound of exit presents an entirely different appearance from that of entrance. It is usually larger and evidently torn from within out.

The injury to the muscles is almost without exception far greater than that of the skin. Often on enlarging the wound of the skin the hand may be passed into a cavity filled with pulpified muscle and gritty fragments of bone. Herein lies the great danger of the gunshot fracture and its high mortality as compared with other fractures, for infection once implanted in this mass of devitalized tissue has such a favorable environment for propagation as to become at once exceedingly dangerous. Yet these fractures if not infected progress favorably; and an excellent rule is to never operate upon rifle-ball fractures if the wounds of entrance and exit are punctate and closed; that is, not bleeding. The punctate wound of entrance closes almost immediately. Usually the wound of exit, unless punctate, does not close quickly, and so nearly all such fractures need operation because of the danger of secondary infection. In other words, a punctate wound of entrance means an undeformed, uncontaminated ball, hence a sterile ball and an uninfected wound. Tumbling and upset balls make larger wounds, and they may be contaminated or carry in clothing.

Fractures caused by shrapnel balls were quite common in the early part of the last war, but were rarely seen after the entrance of the United States. In some ways they are peculiar, having some of the characteristics of fractures caused by spent rifle balls, in that they make small wounds, are often lodged, and, as a rule, do not carry in clothing. Several instances of perforation of the bones by them without complete fracture were observed. It is wise to operate upon all fractures by shrapnel balls, provided the conditions for operative technic are good and there is time. When all the wounded cannot be operated upon and some have to be passed on, the fractures by shrapnel with punctate wounds should be evacuated, as they have a good chance of escaping infection.

Fractures caused by shell fragments, usually termed "fracture by high explosive," are almost invariably contaminated because the jagged portions punch out portions of the clothing exactly corresponding to the striking surface of the fragments and carry the clothing with them into the wounds. If the fragment enters or passes through the bone the patch of clothing is shredded out by the sharp bony fragments and portions of it remain attached to them, while others are distributed throughout the wound.

Most of the moderately sized shell fragments lodge, and the extensive pulpification of the muscles encountered in some wounds by rifle balls is seldom observed; yet, on account of the variations in size and in velocity, almost any variety of wound and fracture may be produced. As will be referred to later (p. 462), it is very important to distinguish between the fractures caused by the shell fragments simply striking the bone, namely, fractures by impact, and those in which the shell enters or passes through the bone, fractures by penetration. In the former the soft parts alone are contaminated, while in the latter the marrow cavity of the bone is likewise contaminated.

INFECTION OF GUNSHOT FRACTURES

Gunshot wounds and fractures become infected in two ways—from without and from within. In the first case there is no infection-bearing material within the wound and the wound becomes infected from the surrounding skin, clothing, etc.; in the second case material bearing bacteria is carried into the wound by the projectile. In the first case antiseptics, such as iodin, are of real value, while in the second case they are of no value, as the wound is already contaminated and contains foreign material. Tincture of iodin, therefore, being the best antiseptic in the conditions met in the field, should be incorporated in the first-aid packet.

As has already been stated, the injuries to the soft parts in gunshot fractures are usually severe, and the tissues are not only sometimes torn to pieces but are actually pulpified, thus producing media very favorable for the pullulation of bacteria. This is particularly true in the case of infection by saprophytic anaërobes, which multiply with extraordinary rapidity in the closed or partly closed wounds in which there is extensive destruction of muscle. In such wounds *gas gangrene may be well advanced in four or five hours.* Usually, however, the period of latency lasts for six hours. The bacteria of suppuration, namely, the streptococci and the staphylococci, take longer than the anaërobes, pullulation becoming active in from eight to twelve hours.

While the anaërobes do not remain in the wound as agents actively detrimental to the repair of fractures, they are destructive to all tissues, including the bone, and by this destructive action favor development of the pyogenic organisms.

Pyogenic infection of fractures not only takes place before operation, but it may occur secondarily during the treatment following the operation. The primary operation, if performed early and properly, can eliminate contamination and prevent infection in the great majority of cases. Secondary infection during after-treatment rarely occurs in wounds previously free of infection, and is almost invariably due to direct transmission by attendants of the virulent forms of streptococci such as S. hemolyticus and S. erysipelatis. Secondary infection should not be confused with "flares," that is, recrudescences caused by insufficient drainage or by traumatism. Secondary infection is prevented by primary closure of wounds and vice versa; its frequency is *proportional*

to the number of dressings, as well as to the *number of cases of infection* in the service, from which contamination may be carried.

The treatment of infection in gunshot fractures does not differ from that in wounds of the soft parts, except that dead bone is not so readily or quickly eliminated as are sloughs of the soft parts, and consequently, as these dead fragments are harborers of bacteria, the infection process is correspondingly prolonged. Especial care, therefore, must be given to drainage in order to avoid pocketing and burrowing of sinuses.

In regard to the use of solutions, such as Dakin's, which dissolve the softer tissues, it is a question whether their employment in the early treatment of fractures, on account of their solvent action, is not destructive to fragments of bone which might otherwise live.

REPAIR OF FRACTURES

The process of repair in gunshot fractures does not differ in principle from that observed in the ordinary fracture in civil practice. As infection markedly influences repair, it is well to consider the uninfected cases first.

I. In the *absence of infection* there is no death of tissue, at least in mass, and new bone is produced to a varying extent by all the osteogenetic tissue, whether attached to periosteum or bone fragments, or contained within them. If there is no comminution the repair does not differ from that of a similar simple fracture caused by indirect violence, except that, as the periosteum has usually not been stripped from the ends of the bones, the repair, as has already been said, takes place more normally and more rapidly. In cases of extensive comminution the new bone forms around the fragments and between them, and, as the broken surfaces present a far greater area than those of a non-comminuted fracture, the formation of new bone is much increased and the site of union correspondingly enlarged, the size and irregularity of the callus depending upon the separation and distribution of the fragments. Osteophytic processes often extend into the muscles, interfering greatly with their function. Nerves may be surrounded and included. Pieces of bone entirely detached from the others and projected into muscles do not, however, produce new bone, but, as has been shown in cases of experimental implantation of bone into tissues distant from bone, are gradually absorbed. The tendency to excessive bone production can be controlled to a certain degree by proper treatment. Traction by stretching the muscles tends to confine the fragments to normal limits, and no drainage-tubes or packing should be introduced between them, as holes or cavities may be formed which close but slowly, if they close at all.

II. **Infection** not only delays union as a rule, but also, by causing entirely or in part the death of fragments, gives rise to obstinate sinuses leading to the dead fragments or sequestra, which do not close until the dead bone is removed, and then often very slowly on account of the irregular cavities left in the callus. Mild infection stimulates bone formation to a certain degree, and the excessive growth of the involu-

crum about the necrosed bone thereby caused frequently results in the production of irregular and exuberant callus which interferes greatly with the function of muscles and joints in proximity to them. Furthermore, long-continued infection, kept up by the presence of dead bone and the abscesses caused by the blocking of drainage by reparative tissue, leads to infiltration of the surrounding soft parts by scar tissue, and this, added to the incisions which have to be made to afford drainage, has most deleterious effects upon the function of the member.

Typical osteomyelitis is exceptional in comminuted fractures on account of the free drainage afforded to the medullary cavity. Not infrequently a limited osteomyelitis is observed in transverse fractures and results in the death and separation of the entire ends of the fragments. This is particularly true of fractures in which the periosteum is stripped from the ends of the fragments, thus depriving them of their nutrition and at the same time allowing infection to enter. Destruction of the medullary artery is a frequent cause of extensive necrosis. Occasionally a missile produces fissures which, on account of the elasticity of the bone, close, entrapping foreign material and thus producing osteomyelitis. Fissures that close, however, rarely lead to extension of infection. It is rather the open fissure, along which infection may extend, but which does not afford sufficient drainage, that gives rise to extensive infection of the marrow cavity. Such fissures, extending through the epiphyses into the joints, may lead to infection of the latter, necessitating amputation in order to save life.

Insufficient drainage of the medullary cavity is a cause of grave spreading of infection resulting in extensive death of bone, and this is why typical osteomyelitis is more common in slight wounds and injuries of the bones than in severer ones. Even deficient drainage of the wounds of the soft parts increases the infection, and therefore prepares the way for the death of the bone.

When necrosis of fragments situated centrally to the forming callus occurs (as, for instance, the ends of the main fragments) a flask-like callus is apt to form containing the sequestra in its cavity. As time goes on this callus is added to peripherally and excavated centrally, on account of the absorption going on about the sequestra, and the flask is thus increased (Fig. 159). This produces a very troublesome condition, necessitating resection of one side of the flask to permit closure of the cavity. (See Operative Treatment, p. 466.)

Repair in injuries of the epiphyses and in the short bones differs from that observed to take place in the diaphyses. There is no medullary cavity, and true osteomyelitis does not occur. On the other hand, infection leads to a troublesome osteitis, characterized by fragmental death rather than necrosis *en masse*.

The peculiarly obstinate infection and suppuration noticed in cancellous bone can be explained by the character of the lesions produced by the projectiles. (See p. 444.) In the contused and hemorrhagic areas infection extends, giving rise to scattered foci of necrosis. In continued infection and from the concomitant disuse the bony trabeculæ

become absorbed and the fatty tissue increases, so that the entire epiphysis becomes softened. This softening is frequently *mistaken by the surgeon for necrosis*, and he may do irreparable injury by cureting out tissue which, with the subsidence of infection and the resumption of function, would again become firm. These cavities do not fill with new bone, and may have to be leveled up by the implantation of indifferent tissue, such as fat.

Besides causing death of bone, injury to the nutrient vessels of a bone has a marked influence upon repair, especially

FIG. 159.—PRODUCTION OF IRREGULAR EXUBERANT CALLUS ABOUT THE NECROSED EXTREMITY OF FRAGMENT IN COMPOUND FRACTURE OF THE FEMUR.

Note the absorption of the interior of the callus. Upon the removal of this sequestrum a flask-like cavity will be left almost if not impossible to close. (By courtesy of R. Leriche.)

FIG. 160.—TRACING OF A RADIOGRAPH IN THE ARMY MEDICAL MUSEUM OF FRACTURE OF HUMERUS.

Although extensive resection of the fragments had been performed, union has taken place by means of the remnants of the periosteum. Note the deformity due to insufficient abduction.

in infected fractures. This is evidenced by a rarefaction of the bone deprived of its nutrition and a lack of new bone formation, and not infrequently by non-union. Bone-grafts do not take well in such cases.

Non-union rarely happens in comminuted gunshot fractures, and should not occur in non-comminuted fractures properly treated. I have never observed it in comminuted fractures in which the fragments were not removed; but it occurs frequently after improper resection of the fragments (Fig. 160).

If the fragments are kept in a reasonably good position, union almost

invariably occurs by means of the involucrum, even in the presence of extensive necrosis of the ends of the bones. If by mischance the involucrum should break, union usually recurs rapidly; but occasionally, particularly in old cases in which efforts toward repair seem to have exhausted themselves, definite non-union results. In such cases the extremities of the fragments are found to be rounded and the medullary cavity to be plugged by eburnated bone. In such cases union will never take place until the ends of the fragments are resected or the continuity of the medulla re-established by an inlay graft.

TRANSPORTATION AND SPLINTING OF THE WOUNDED HAVING FRACTURES

The treatment of the wounded with fractures is divided into *three stages*, namely, (1) that between the place where they are wounded and the evacuation hospital, (2) that at the evacuation hospital and between there and the base hospital, and (3) that at the base hospital. A fourth stage might be added, comprising the after-treatment, vocational training, and transportation home. But, as the treatment at the base hospital is supposed to carry the soldier well on to convalescence, this last stage would not ordinarily be of great importance in other aspects than that of vocational training. However, in the Great War, on account of the lack of hospitalization in France, both the British and American Armies had to transport wounded home before they reached the stage of convalescence ordinarily achieved at a base hospital. This fact does not modify the surgery to be practised at the base, but for those who have to be transported before they should be changes the character of the base hospital to that of an evacuation hospital.

(1) In the *first stage* of treatment the patient is supposed to receive the first-aid dressing and have a splint applied where he falls. From there he is usually transported to a first-aid post, where the splinting is revised and any necessary change made in the dressing; for instance, to arrest hemorrhage. Here, also, the preventive treatment of shock is commenced. From the aid post to the evacuation hospital he is usually transported by motor or horse-drawn vehicle.

The splints for this stage of the treatment must necessarily be simple, few in number, and portable, in order that they may be carried *on to the field* and quickly applied.* As they must be applied in the greater number of cases by the enlisted men of the Medical Corps, it is necessary that these men be well drilled in their application. The importance of this was exemplified by the very satisfactory results attained in the transportation of the wounded from the field in the American Army.

The splints that have proved most satisfactory on the field are the Thomas half-ring leg splint and the Thomas hinged arm splint. These, with the exception of the Cabot posterior wire splint and some of the accessory splinting material, are sufficient for the transport of all fractures of the upper and lower extremities. Both of these splints afford

* See Appendix (p. 499) for list of splints and splinting material to be carried by a tactical division.

traction, which is the most important factor in preventing secondary injury in the way of laceration of the soft parts by the jagged ends of bone. They also afford sufficient lateral support which, supplemented

FIG. 161.—THE HINGED TRACTION ARM SPLINT (MURRAY) AND THE THOMAS TRACTION ARM SPLINT. The hinged splint should be used for transportation and is also to be preferred for treatment. Used for injuries of the shoulder, arm, elbow, and forearm.

by accessory splinting material such as the wire ladder or wood splints, provides the necessary fixation.

The ring of the Thomas hinged arm splint (Figs. 161, 162) is passed over the upper extremity from which the sleeve has been removed, and traction is made by zinc oxid adhesive strips which, having been applied

FIG. 162.—APPLICATION OF THE THOMAS HINGED ARM SPLINT (MURRAY) FOR FIELD TRANSPORTATION OF FRACTURES OF THE HUMERUS.

Note the method of slinging the arm in the splint. Traction is made by adhesive applied to the forearm and tied over the end of the splint. On account of the slight traction requisite in these fractures the Spanish windlass is seldom necessary.

to the palmar and dorsal aspects of the forearm, are then attached by their ends to the end of the splint, the traction being tightened by twisting a short piece of stick or nail between the ends of the plaster (Spanish windlass, Fig. 163), although for the upper extremity the traction may

usually be tied tight enough without the use of the additional adjustment by the Spanish windlass. In field work traction should *never* be made by any band or hitch attached around the wrist.

The Thomas half-ring thigh and leg splint (Fig. 163, B) differs from the full ring splint in that, there being only half the ring the splints can be packed together, consequently occupying far less space and adding greatly to their portability. Furthermore, they do not have to be passed over the wounded limb and are more readily adapted to different sizes of limb. For these reasons they were preferred in the American Army

FIG. 163.—A, THOMAS TRACTION THIGH AND LEG SPLINT WITH PEARSON'S SUPPLEMENTARY LEG PIECE ATTACHED. B, THOMAS HINGED HALF-RING TRACTION THIGH AND LEG SPLINT. (Blake-Keller.)

for field work to the full ring splints. However, more care has to be taken in their adjustment to prevent their sliding up over the tuberosity of the ischium against which they are supposed to bear. Care, therefore, must be exercised to see that the strap passing over the groin is tight enough to prevent this. Care must also be taken to see that the half-ring is turned well down at right angles and that the splint is crowded up enough against the tuberosity of the ischium to keep it in that position. The end of the splint with the limb must also be elevated and attached to the stretcher bar (Figs. 164, 165).

For fracture of the lower extremity neither the trouser nor the shoe is removed on the field, the trouser being cut simply enough to expose the wound for the first-aid dressing. Traction in the field is made by one of the hitches (Fig. 166) applied over the boot, traction being tightened and adjusted by the Spanish windlass method.

The Thomas splints are to be used for all fractures of the lower extremity from the pelvis to the ankle. Fractures of the ankle and foot

Fig. 164.

Fig. 165.

FIGS. 164, 165.—SPLINTING OF FRACTURES OF THE FEMUR FOR TRANSPORT FROM THE FIELD.

The clothing and boot are not removed. One of the hitches shown in Fig. 166 is placed over the boot; the splint, Thomas or half-ring Thomas, the latter shown applied and snugly adjusted against the tuber ischii. The Spanish windlass is then twisted, drawing the leg well down, when it can be moved without pain; the supporting slings are then knotted; the wire foot support and splint rests are then attached to the splint and the foot tied to the former in order to prevent rotation; and stretcher bar is then attached to the stretcher and the splints tied to it as shown so as to prevent lateral as well as vertical motion. In transportation with the Thomas splints it is absolutely essential to have the splint elevated by the stretcher bar or splint rest.

and those of the lower part of the leg in which traction cannot be applied are splinted with the Cabot posterior wire splint which can be supplemented by wire ladder splinting if necessary.

Fractures of the hand and wrist are best supported on wire ladder splinting, or the hand and wrist splints (Fig. 167) may be used. The use of these last splints should not be continued long, because it is apt to result in stiffness of the fingers.

For many fractures of the shoulder-girdle and in some of the arm and forearm, for which the other splints are not available or cannot be used on account of extensive wounds, the triangular sling is of great aid.

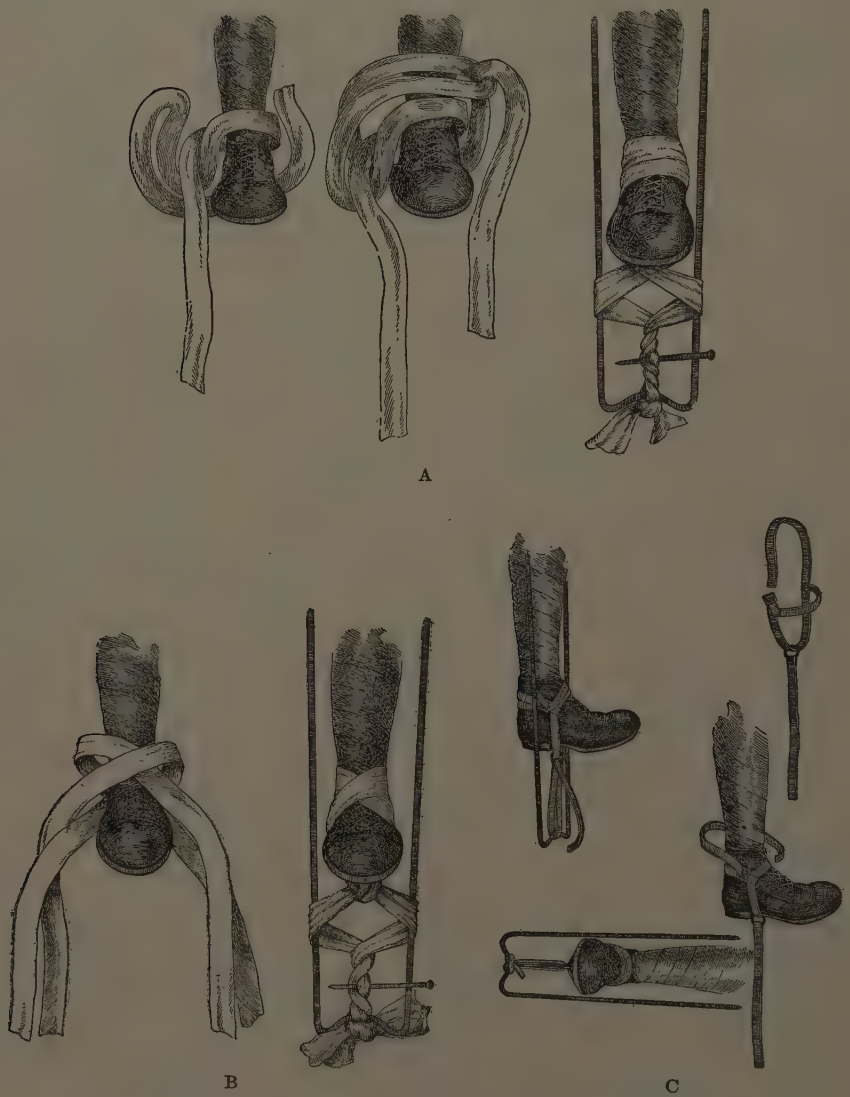


FIG. 166.—TRACTION HITCHES FOR FIELD TRANSPORTATION.
A, Collins' hitch; B, Poliquen hitch; C, Adjustable traction strap and saddle girth hitch.

Fractures of the spine and pelvis are transported by means of the snowshoe litter (Fig. 168). For the hip the long Liston splint (Fig. 169) is used either alone or in connection with the snowshoe litter, although they can be satisfactorily transported with the litter alone.

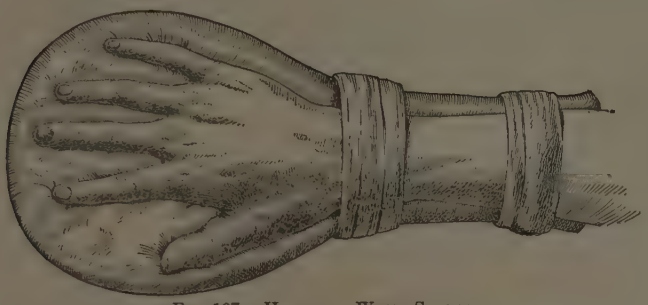


FIG. 167.—HAND AND WRIST SPLINT.
Made of thin board padded so as to be convex under the hand.

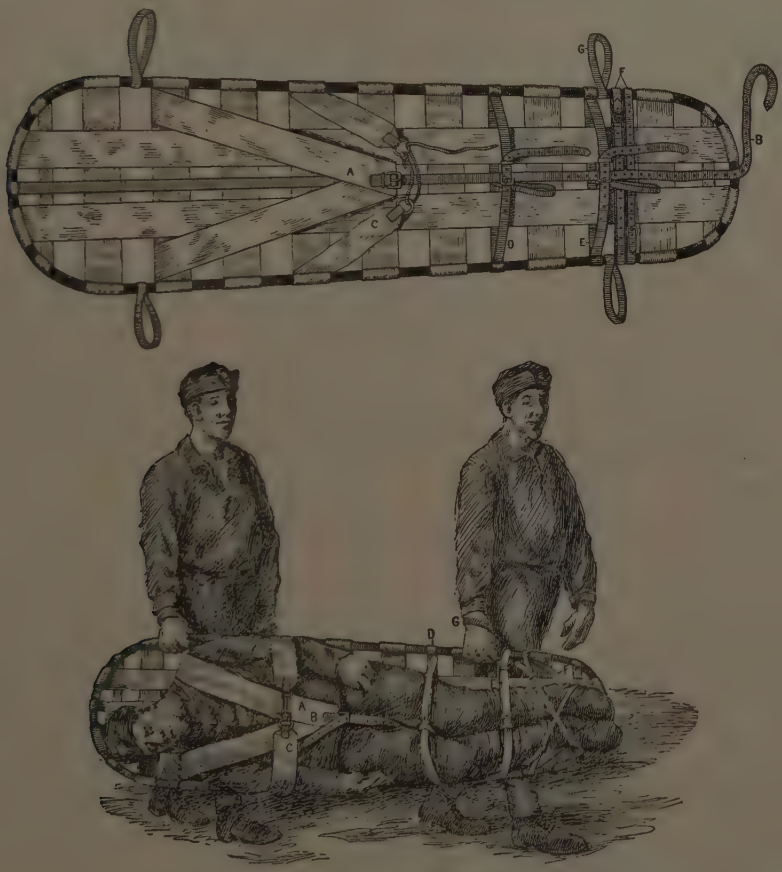


FIG. 168.—SNOWSHOE LITTER.
The frame is made of the steel tubing used for aëroplanes. The illustrations show its construction otherwise and the method of using it. Although ordinarily carried by four men, it holds the patient so securely that it can be carried by one side as shown, making it exceedingly practical for trench work, as corners may be turned without exposing the wounded man. Although useful for any severe injuries, it is particularly adapted to the transport of spinal and pelvic cases.

(2) Treatment in the *second stage*, comprising that in the evacuation hospital and transportation from there to the base hospital, con-

sists of first the operation (described elsewhere) and then the splinting for further treatment or transportation.

In evacuation and mobile hospitals, as their names imply, the patients are only retained long enough for them to be treated for shock, operated upon, and put in condition for their transportation to the base hospital, in which their treatment is carried on normally until convalescence is established. There are always a certain number of patients whose condition is so serious as to prevent their transportation, and therefore the evacuation hospital has to be provided with the means to carry on their treatment. This treatment may be continued fairly satisfactorily by the splints which are used for transportation and without the paraphernalia which is installed in the base hospital. This not only provides the greatest comfort for the patient but also leads to the best results.

In the evacuation hospital it is best to have splint teams organized who have complete charge of the splints and accessory apparatus and whose duty is to splint fractures at the operation and to see that the splints are properly adjusted at the time of the evacuation of the

FIG. 169.—APPLICATION OF THE LONG LISTON SPLINT FOR FRACTURE OF THE HIP AND PELVIS.
Traction can be applied by means of a padded perineal band passing between the legs and attached to the upper end of the splint, which provides countertraction, and by attaching the foot to the foot piece by one of the hitches illustrated in Fig. 166. The splint in order to obtain traction must be relatively longer than that depicted.

wounded. It is also their duty to see that the supply of splints is kept at the standard, and that the splints are returned in the ambulance in place of the splints brought in on the wounded, as only in this way can the supply of splints be maintained in the first-aid posts and on the field. In the evacuation hospital the character of splinting changes from that on the field only slightly, the need for transportation of the wounded further on still existing.*

At the evacuation hospital it is wise to change from the half-ring to the full ring Thomas thigh and leg splint (Fig. 163, A), as the latter is more fool-proof and is not so apt to get disarranged in the period covering the transportation from the evacuation hospital to the base which, exceptionally, may occupy several days. The Thomas full ring thigh and leg splint for transportation use is not made in sizes to fit the patient, only two sizes being furnished in the American Army. The rings, therefore, have a tendency to slip over the tuberosity of the is-

* See Appendix (p. 498) for a list of splints, splint accessories, and dressings for an evacuation hospital.

chium, against which they should bear, and the upper thrust of the splint is then taken up against the perineum. This, although painful to the patient, yet maintains traction. For transportation purposes the splint has to be kept straight, although, as will be seen later, it is impossible to treat fractures of the thigh properly unless the splint is bent or a supplementary hinged piece attached to it. As the extended position of the knee is not only uncomfortable, but tends to deformity in most fractures, it is necessary, in the application of the splint for long transport, to see that sufficient support is provided behind the knee so as to at least prevent its sagging. This may be accomplished by a padded board splint or, better, wire ladder splint, inserted between the slings of the Thomas splint and the limb.

For certain fractures of the spinal column and for some fractures of the hip and pelvis plaster of Paris should be used in order that their transport on from the evacuation hospital may be safer and more comfortable. For the spine the plaster is applied in the form of a plaster

FIG. 170.—APPLICATION OF PLASTER-OF-PARIS SHELL FOR FRACTURES OF THE SPINE.
In lesions above the sixth thoracic vertebra the shell should be extended to include the back of the head.

jacket or plaster shell; for injuries of the pelvis and hip, in the form of a spica.

The plaster-of-Paris shell (Fig. 170) is applied to the patient lying prone and in such a position as to preserve the normal curve and outline of the back. The shell is best made of fifteen to twenty thicknesses of crinoline cut out to the shape of the shell. These should then be impregnated with a plaster cream and applied over stockinet. In cases of fracture above the sixth thoracic vertebra the shell should also include the neck and back of the head. In applying the plaster spica care should be taken that the bony points are well covered by saddler's felting or cotton, and it is wise in this case, too, to cut out pieces of crinoline shaped to the outer side of the thigh and to the portion of the spica which goes around the body. This, when applied as in the manner described for the plaster shell, will save a great deal of time and a great many turns of bandage.

The method of applying traction to fractures of the lower extremities is also changed at the evacuation hospital. Until the patient

reaches the evacuation hospital traction is applied over the boot, but this cannot be sustained for a long time, as pressure sores soon develop over the dorsum of the ankle and tendo achillis. At the operation at the evacuation hospital adhesive traction bands are applied. In the case of the upper extremity, as the tractive force applied is only slight, zinc oxid adhesive may still be used, although it is apt to slide upon the skin, but for the lower extremity and for the upper extremity, where strong traction has to be applied, it is far preferable to glue bands of muslin, or of several thicknesses of gauze, or, preferably, of good canton flannel to the skin. The old-fashioned diachylon moleskin plaster is very efficient, but is not generally available.

For gluing to the skin two varieties of glue are used, the more satisfactory of which is Sinclair's, although Heussner's glue* is satisfactory if great care is exercised in making it up and in preventing its evaporation, as otherwise it is apt to cause irritation and blistering. Great care is needed also in the preparation of Sinclair's glue, which must be made from the very best cabinet makers' glue. It is better that the reaction of the glue should be neutral. Sinclair's glue is applied with or without shaving the skin. If the skin is not shaved the last strokes of the brush in applying the glue to the skin should be directed so as to turn the hairs toward the body. The skin must be shaved before using Heussner's glue or adhesive plaster. Great care should be taken to apply the hands smoothly and to avoid wrinkling or creasing, as this is apt to cause blisters. A spreader is always introduced between the ends of the traction bands in order to avoid pressure upon the malleoli or the condyles of the humerus, as the case may be. It is important that this spreader should not be too long, as otherwise the separation of the lower parts of the glued bands is apt to strip the epidermis off and thus produce blisters. Itching is one of the first symptoms of blistering, and if this is present, the band should be carefully examined and even removed, for if blistering is once established the traction bands can no longer be applied. After gluing on the bands, a smoothly applied bandage should be applied over them so as to promote an even adhesion of the bands and to prevent the stripping just referred to. Traction may be applied directly after the use of Heussner's glue. It is better to wait from five to ten minutes before applying traction in the case of Sinclair's glue. As traction straps should remain on as long as possible, it is very important that the skin should be thoroughly cleansed before applying them. As Sinclair's glue is an aqueous preparation, it is sufficient to cleanse with soap and water, carefully removing the soap. In the case of Heussner's glue, the water should be removed with alcohol and the skin be perfectly dry. All traction bands should be changed as soon as they begin to separate from the skin. This usually takes place in about two weeks, and is probably due to the normal desquamation of the epithelium. Occasionally the bands stay on for longer periods, but if a band is allowed to become partially detached, so much tension is applied to the epidermis by the remaining attached part as

* See Appendix (p. 497) for formulæ of Sinclair's and Heussner's glues.

to produce great danger of pulling the epidermis off and producing blisters.

In regard to the proper time for evacuating the patients from the evacuation and mobile hospitals to the base, it has been well proved that the most favorable period is immediately after the operation and before repair has set in. This brings the patient to the base hospital in time for his apparatus to be changed and his fracture put in proper position before repair is well under way, and consequently there is no setback. This period may be stated to be at any time within the first three days after operation. If the patient cannot be transported before this time, it is far better for him to be retained until repair is so well accomplished as to obviate the danger of refracture or disturbance at the site of fracture. After three days, infection, if it takes place, is apt to be at its height, and until this has disappeared there is great danger of causing an increase in infection by transportation. Fractures of the femur stand transportation very poorly, and therefore it is wise in the evacuation hospital to provide for the retention of a few of these cases, because some of them, on account of shock, cannot be transported during the favorable period. Fractures of the arm, forearm, and leg can be so well protected during transport as to make it comparatively safe for them at any period. Unless there is great danger of a retreat some of the appliances to be mentioned in connection with the base hospital, such as the suspension frame, should be available at the evacuation and mobile hospitals.

(3) In the *third stage* of the treatment the patient has arrived at the base hospital. Here conditions are more stable and the patient is supposed to receive treatment best adapted to the fracture from which he suffers. No matter what the exigencies may be, there will always be found room at the base for the patient for whom transportation is decidedly detrimental. Therefore the aim at the base hospital should be to institute and carry out the treatment which is best for the patient. It will be found more convenient to set aside a separate service for the fractures, as they need special apparatus in the way of splints and appliances and special *x*-ray facilities. There should be a portable *x*-ray apparatus for each 150 patients. It is well also to develop a staff who are specially instructed and skilful in treating fractures. This may be done without detriment to the rest of the staff if they are each required to serve in turn on that service.

Experience of the war has amply proved that the methods of suspension in vogue in the British, French, and American Armies lead to the best results, contribute markedly to the comfort of the patient, and save life. The methods for the suspension of fractures of the different limbs will be considered separately, but, in general, the suspension frames or scaffolding are the same for all fractures. In special fracture hospitals it may be well to build a scaffolding the length of the ward. This in some of the British hospitals was constructed of a pair of longitudinal bars running the length of the ward each about 0.10 x 0.075 meter (4 x 3 inches) in section. Both of these were about 2 meters

above the floor, one passing 0.85 meter (2 ft. 6 in.), the other at 2.25 meters (7 ft. 6 in.) from the wall, the latter thus passing directly over the foot of the bed. Over these bars lighter bars were placed running, in general, in the direction of the bed, and from these the suspension was carried out. To provide for traction, such as for the femur, a post was used the lower end of which was stepped into the floor, the upper end being attached to the bar over the foot of the bed. In the American Army the form of frame illustrated in Fig. 171 was used and found

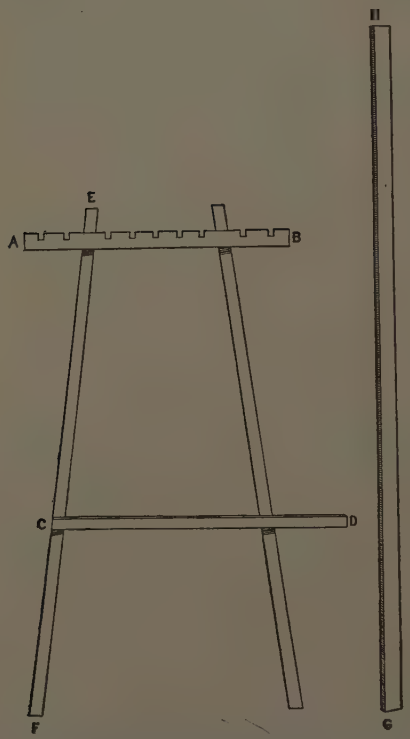


FIG. 171.—SUSPENSION FRAME.

The vertical and lower cross members are ¾ in. (M. O. 021) thick and 2 in. (M. O. 05) wide. The upper cross and the longitudinal members should be at least 2½ in. (M. O. 06) wide. AB = 40 in. (M. 1. 0). CD is cut long so that it can be adapted to different widths of beds. EF = 80 in. (M. 2. 0). GH = 10 ft. 4 in. (M. 2. 65). The separation of the vertical members at the height of the cross members CD and of the mattress should be that of the bed posts. The members are fastened together by screws or bolts. The frame may be made rectangular, but then is not so rigid, particularly for narrow beds.

very practical because it was readily constructed from wood, could be easily knocked down and transported, and correspondingly easily set up. This frame was first used in the hospital founded by Mrs. H. P. Whitney at Juilly in the service of Dr. H. H. M. Lyle, early in 1915, and was introduced from there to the American ambulance hospital by Blake. The truncated **A** form was adopted as being more rigid than right angular construction. For base hospitals the frames may be constructed of any clear wood. For mobile and evacuation hospitals a strong wood such as ash is preferable, and as the size of the bed is known

the frames are best fully finished and put together with bolts with wing nuts, so that they can be easily taken down and erected. With each head and foot frame there should be three longitudinal bars. Two of these are necessary for each set-up of the frame, the third bar being necessary for some cases. The extra bars not used as overhead longitudinal bars may be cut up for extensions and braces such as are exemplified in Figs. 178 and 184. From the two overhead longitudinal bars cords are attached with handles so that the patients can lift themselves up in bed.

In general, suspension is carried out to these frames by cords attached either to the limbs or splints. These pass through pulleys having weights attached at their other ends. These weights serve, in the case of suspension, to counterbalance the limb, and in case of traction to produce the necessary force. For suspension of the lower limb a trolley will be found to be of great convenience. This trolley consists of a short bar either running on a rod attached under one of the longitudinal bars (Figs. 184, 185) or simply sliding on one of the longitudinal bars by means of the strap-iron hooks. The trolley permits the patient's position to be shifted up and down in the bed without changing the angle of suspension of the limb. The pulleys are the ordinary iron pulleys with a hook which may be hooked into the strap-iron hooks.

As has already been stated, the splints used for the transportation of patients do not always provide the best position for treatment of fractures unless they are bent or otherwise modified. The methods of bending these splints and the reasons will be stated under the treatment of each fracture.

In the transport of patients traction has to be carried out on the fundamental principle of the Thomas splint, which consists in pulling down the limb to the end of the splint, the countertraction being taken up by the pressure of the ring against the body. Although there are many advocates of this method of applying traction to the exclusion of all others, traction applied by weights affords many advantages. In the first place, it can be absolutely regulated in amount; second, it is always operating; third, it is much better borne by the patient; fourth, it is better adapted to the bent position of the limb. It is also adapted to the methods of producing direct skeletal traction, which is much more efficient than the traction carried out by adhesive bands.

In regard to the principles of applying traction, the main thing to be remembered is that sufficient weight should be applied at the onset to reduce the fracture; that is, overcome the overlapping. As soon as the deformity is reduced, the traction is diminished to an amount just sufficient to keep the fragments in position. For example, 20 to 25 kilos (44 to 55 pounds) may be necessary to reduce a fracture of the thigh. Reduction, which should take place in a few hours, having been accomplished, the weight is usually reduced to less than one-half of this amount. By carrying out traction in this way the least damage will be done in the way of overstretching the ligaments of joints. By the time the patient reaches the base hospital his fracture is often well on

toward repair and a large initial traction weight is imperative, as there is no time to lose if reduction is to be accomplished.

OPERATIVE TREATMENT OF FRACTURES

No operation should be performed until the wounded reach a place where formal aseptic surgical treatment can be given—except in case of hemorrhage, for which neither a tourniquet nor a tampon should be used, but the bleeding point caught by a forceps. The tourniquet is provocative of gas gangrene, and the tampon, of infection. When either has to be used the patient should be a rush case for operation.

Every fracture should be operated on with the exception of those in which infection is improbable, such as those caused by a bullet in which both wounds are punctate. Manifestly, operations should be done at the earliest possible moment. Operations in the first six hours, that is, before the bacteria multiply, are usually successful. After twelve hours success is doubtful.

The operative technic is extremely important, for upon the success of the primary operation in removing the causes of infection depend the entire after-course of the wound and perhaps the life of the patient. The operative treatment resolves itself into two categories: that of the soft parts and that of the bones.

In general, wounds of the soft parts complicating fractures should be treated in the same manner as those of the soft parts alone. If the operation is methodically and correctly performed it is obvious that when the whole of the superficies of the wound surfaces is removed all foreign material are removed as well, so that theoretically there is no need of *x*-rays to determine the presence of missiles; but practically an accurate localization of the *x*-ray gives valuable information in helping to determine the course of the projectile and the approach, especially if counter-incisions have to be made.

Wounds treated in this way may be closed by primary, delayed primary, or secondary suture.

While from 98 to 99 per cent. of the uncomplicated wounds of the soft parts in selected cases can be successfully closed, the structures involved are, as a rule, of minor importance, and risks may be taken that would be unwarrantable were the wounds complicated by fractures. Nevertheless, most fractures may also be closed in this way if certain points in the operative technic are carefully observed; indeed, in many cases, as will be shown, they may be sutured primarily with as much impunity as wounds of soft parts alone. As a general principle, however, it is more prudent to practice delayed primary suture when a fracture is present on account of the difficulty of removing foreign materials from among the bone fragments. Herein lies the importance of distinguishing between fractures by impact and fractures by penetration.

In the former case the projectile does not enter the medullary canal, and the wound may be sutured as though it were an uncomplicated wound of the soft parts. The stitches should be interrupted and spaced sufficiently to permit a certain amount of drainage and yet

accurately approximate the tissues. A few strands of silkworm-gut may be inserted to serve the double purpose of draining the wound and providing a tell-tale as to the bacterial flora it may contain. They are removed at the end of the second or third day and cultured to determine whether the wound may remain closed or should be reopened.

If the missile has penetrated or perforated the bone, however, the medullary canal must be considered to be contaminated, and must be laid open and explored. To do this it is nearly always necessary to remove some of the fragments. Absolutely detached fragments should always be removed, since they have become foreign bodies and will surely necrose should infection supervene. Unhappily, their removal seldom affords sufficient exposure of the medulla, and therefore fragments still attached to their periosteum must also, as a rule, be cut away. The greatest care must be exercised in excising them, and only enough and no more should be removed. Care should be taken to leave at least one or more, if possible, to preserve the continuity of the shaft. In other words, if a resection is done it should be lateral and not transverse in character. When a piece has to be removed it should never be torn or pried away; it must be cut out, leaving its outer layer adherent to the periosteum. This can only be done by one instrument, namely, the cutting periosteum elevator of Ollier (Fig. 172). The edge of this rugine must be kept as sharp as a razor, and as several may have to be used during an operation, a number of them, of various sizes, should be at hand. The fragment to be separated must be held firmly in a bone forceps while its outer layer is sliced off by lateral movements of the rugine. The medulla having been sufficiently exposed, all loose fragments and pulpified medulla should be removed, as the latter is apt to be filled with particles of clothing.

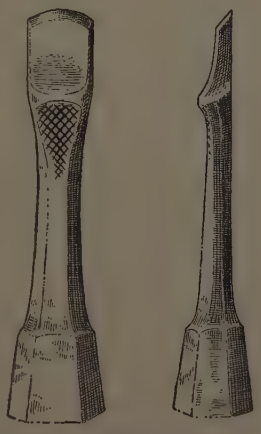


FIG. 172.—CUTTING PERIOSTEOTOME OF OLLIER.

The instrument is used not by pushing, but by making lateral movements by which its keen edge is made to shave off thin layers of bone together with the periosteum.

In the case of fractures in which the missile has perforated the bone, comminution is frequently more marked at the side of the bone opposite to the wound of entrance, and the soft parts there are more likely to be filled with contaminated bone fragments, and therefore to need more careful treatment than those on the side of entrance. Consequently, in such a case it is better to lay open the wound on both sides of the limb.

For fractures by penetration great judgment must be exercised in practising primary suture. The nature of the missile, the time elapsed since wounding, the character of the wound and its situation, as well as whether the patient is to be kept under observation or evacuated, must be taken into account. It is wiser for an inexperienced surgeon to

practice delayed primary suture. Certain fractures, such as those of the femur, which are surrounded by thick muscles in which the anaërobic bacteria are apt to proliferate, should not be closed primarily save under exceptionally favorable conditions. If infection supervenes in a closed wound it is much more violent in character than in an open one, and results in a far greater setback to convalescence.

If there is grave doubt as to whether the wounds are infected (as, for example, in the case of delay before operation exceeding eight hours), it is better not only to leave the wounds widely open but also to use a complete Carrel installation so as to remove the wound secretions as completely as possible during the first few days following the operation. If the patient has to be evacuated the Carrel treatment is impracticable, and two or three layers of vaselined gauze should be laid in the wound. The wound should never be packed on account of the danger of anaërobic infection (gas gangrene) and of the traumatism caused in removing the packing.

A fracture which is transported after operation is more likely to become infected than one retained in the service of the operator, and, consequently, as many fractures as possible should be kept in the hospital where they have been operated upon. If they must be evacuated, delayed primary suture may be done at the hospital in which the patient is ultimately retained. It is extremely important that the series of hospitals through which fractures pass should be in close relation with one another, so that the results of operations may be closely followed and treatment consistently carried out.

Operations in Infected Cases.—In obviously infected cases successful primary suture cannot be hoped for. Tissues which have already developed protection should not be excised, but all dead and foreign material must be removed, and free and efficient drainage afforded. The incision should be free enough to enable inspection of the entire wound by sight, but the operation must be gently done and no indiscriminate rooting with the fingers is permissible.

In cases of gas infection (B. welchii) the incision should be very free and all dead muscle removed. In exceptional cases the entire muscle may have to be excised. In any case the incisions should reach into freely bleeding muscle. It is to be remembered that the gas infection extends along the axis of a muscle and is often limited by the muscle sheaths. Incisions should, therefore, be longitudinal, in the axis of the muscle, and never transverse.

In infected fractures it is usually unwise to resect or remove any attached fragments; it is better to wait until the dead or dying portions of bone are sequestrated.

All such wounds should be left freely open, with gauze laid lightly in them. Paraffined gauze does not stick, but ordinary gauze drains better, and may be used when it can be left in until it becomes loosened of itself. It should never be torn out. It is sufficient to keep the exposed parts of the wound well cleansed with soap and water, and hydrogen peroxid if obtainable, afterward washing with alcohol or ether.

The use of drainage-tubes is bad practice, for they only drain locally and allow the surface of the remainder of the wound to adhere and form pockets. If drainage is indicated it is advisable to employ the Carrel method of using many small tubes and intermittent irrigations. It is obvious that an infected fracture must not be secondarily sutured until all dead bone is eliminated.

Resection.—Typical resection (*i. e.*, removal of all the fragments) of diaphyseal fractures is, in general, to be condemned. Good results have been obtained by surgeons skilled in the technic of resection, but it is not a procedure to be recommended (Fig. 160). The resection should be confined to the removal of only sufficient bone to expose the medullary canal (*vide supra*). Resection of fractures of the articulations is sometimes necessary. (See chapter on Joints.)

Internal Fixation.—Systematic plating, banding, and wiring of compound fractures of war have had an extensive trial and are almost universally condemned. In exceptional cases this procedure may be practised when a fracture cannot be retained in reduction by other means, but such cases are rare. It is often a temptation to band or wire long splintering fractures, but equally good results can be obtained otherwise without the risks of the operation. Internal fixation of an infected fracture is, as a rule, bad surgery.

Operations for Sequestra and Bone Sinuses.—Nearly every case of infected war fracture unites with sequestra in the callus. The sinuses resulting therefrom are difficult to close and often keep a soldier, who is otherwise perfectly well, from active duty for months and even years. They will not definitely heal until the necrosed bone is removed, and this should therefore be done at the earliest possible moment, not only to enable the sinus to close, but to avoid osteitis and excessive formation of callus (Fig. 159).

Judgment must be exercised as to when to operate. If the operation is performed before the dead bone has become separated it will be a failure, because the traumatism provoked in removing the necrotic portion leads to further necrosis. There is also great danger of refracturing weak unions.

The moment to operate is when the dead portions have been detached from the living, at which time they can be picked out of the sinus with the least traumatism. Usually this occurs in six weeks, but the time is influenced by the amount of blood-supply to the parts. In weak unions it may often be wise to wait for the growth of more callus, but it must be remembered that an area of absorption is being created about the sequestrum, and the operation should not be postponed until disagreeable cavities are formed.

The best way of determining the presence and location of sequestra, if they cannot be felt by the probe, is by *x*-rays. Stereoscopic plates should be taken by which the sequestra can be localized, standing out by themselves surrounded by a clear interval between them and the less dense callus. In this way their exact number and location can be determined and every one subsequently accounted for at operation.

The trouble and expense of stereoscopic plates are far less than those of several operations and the cost of months of treatment thereby entailed.

Operations for sequestra possess none of the excitement of abdominal surgery, but are even more difficult and require the most painstaking care. As a rule the sinus and scar are excised and the opening thus made used as the approach, unless the sequestrum has been located on the other side of the bone, when an incision over it should be made. The dissection is carried out along the sinus, and if the necrotic bone is within the callus the periosteum should be carefully lifted. As little as possible of the callus should be removed, unless it is necessary to resect walls of cavities. By efficient sponging the dead white sequestrum can be seen and removed. Others, if present, should be sought for in the same way; the stereoscopic plates being on view so that their relations with one another may be compared. Blind curetage of a bone sinus is most reprehensible.

The aniline antiseptic dyes—methylene-blue, gentian violet, flavine, or brilliant green—may be used to stain the sinuses and are of help, but they are not so reliable as stereoscopic *x*-ray plates. It is difficult to obtain penetration of the stain throughout the sinuses.

After removal of the sequestra, in the presence of a reasonably clean field the ends of the incision may be approximated, and drainage may be dispensed with unless evidently needed, when light gauze packing should be employed.

Sometimes when the operation to remove sequestra is deferred for too long a period, particularly when large portions of the main fragments necrose, large cavities are formed more or less completely surrounded by an irregular callus (Fig. 159). Such cavities, unless operated on before the medullary cavity of the main fragment is plugged by new bone (thus stopping all regeneration of bone from that source), are almost incurable and sometimes demand amputation or wide resection of the whole area, including the dense bone closing the medullary cavity. A resection of this extent produces crippling shortening, as a rule, unless a bone-graft can be used. If, however, the operation is performed at an early date it will suffice to resect one wall of the cavity, preserving the periosteum covering the resected callus, and thus allowing the soft parts to collapse and obliterate the dead space. In such operations all the old granulations and cicatricial tissue lining the cavity should be carefully excised so as to allow the periosteum of the side removed to come into direct contact with the callus remaining on the opposite side. When the muscles cannot fall into and obliterate the cavity, transplants of fat should be used. If active infection is present it is better simply to remove the dead bone and leave the wound freely open, waiting until the infection has subsided before attempting to fill the cavity and close the wound.

Vicious Union.—Many cases of vicious union demanding correction come to base hospitals. They are often complicated by dead bone and fistulæ, and it is usually advisable to get rid of the latter before revising the union. In some cases with quiet sinuses showing no signs

of active infection the dead bone may be removed and the fracture revised at the same operation; but the wound, under such circumstances, must not be closed. Non-infected and closed fractures may be revised by simple refracture.

The methods employed to revise fractures obviously depend upon the site and the nature of the mal-union.

Internal fixation is seldom necessary. If the fragments cannot be maintained in good relation by fixing the limb in proper position, an inlay graft may be of value. Repair of fractured callus is very rapid if it is fairly recent. After several months, however, it loses its vascularity and repair is slow, so that operation on these cases should not be deferred.

Non-union.—In true non-union the ends of the bones become healed over and the medullary cavity plugged with dense bone. Union will not take place unless this bone-plug is cut away and the medullary cavity made continuous. Non-union is generally caused by loss of substance (*i. e.*, removal of a section of bone either by the projectile or by the surgeon), and therefore, if all the dense material forming the ends of the bones is cut away, considerable shortening results. Hence bone-plating should not be used, for it is decidedly unwise to put on a plate and leave a gap between the bone ends. The treatment of these cases is an inlay graft by the Albee method. The channel cut to receive it passes through the dense ends, and thus the medulla is made continuous by means of the medullary surface of the graft. The ends of the fragments are not removed, and the bone is therefore not shortened by the operation.

Delayed union is best treated by the use of the member. An ambulatory apparatus such as the Delbet (Fig. 193) may be employed in the case of the lower limbs. Injection of blood between the ends of the fragments should be made in refractory cases.

SPINE

The seriousness of gunshot fractures of the spinal column, excluding associated injuries to neighboring viscera, depends almost entirely upon the concomitant injury to the spinal cord and nerves. For transport from the field the most satisfactory apparatus is the snowshoe litter (Fig. 168), and later on, after operation, a plaster-of-Paris shell (Fig. 170—see page 457). Gunshot injuries of the spinal cord are treated elsewhere, which therefore narrows this particular consideration of the subject to the indications for operation to the transport and to the treatment of the bone lesions in these cases.

Fractures produced by rifle balls in which there is no reason to believe that contaminated material has been carried in by the missile should, as a rule, not be operated upon if there are no symptoms pointing to injury of or pressure upon the spinal cord. The indications for operations in these cases therefore depend upon the symptoms of injury to the cord and are considered elsewhere. There are rare cases, however, in which later injury to the cord may be presupposed and should

be operated upon, as, for instance, the presence of a rifle ball in the spinal canal, such a case having been observed by Blake. It should be borne in mind in this connection that hematomyelia is quite common in gunshot injuries of the spinal column and that these cases usually do well by expectant treatment.

Nearly all the fractures of the spinal column by high explosives should be operated upon. In most of these the shell fragments lodge and almost invariably entrain pieces of clothing or other contaminating material. Consequently the dangers of infection and suppuration are great and operation should be performed if the conditions in the hospital in regard to technic, etc., permit. Oftentimes the pressure is so great in the evacuation hospital that the hopeless cases have to be passed by, and therefore the question arises whether transverse lesions of the spinal cord should be operated upon, but this question must be determined by the circumstances surrounding the case as well as by the humane side. Obviously, if the symptoms of transverse lesion of the cord are produced by pressure which can be relieved by operation, the operation should be done at the earliest possible moment in order to be successful.

Most operations for fractures of the spinal column are, in reality, exploratory laminectomies. Sometimes missiles lodge in the body of the vertebræ, which renders their extraction extremely difficult; but this may be accomplished sometimes by working between the transverse processes or even across the vertebral canal. In my own experience the telephone in connection with a Volkmann spoon instead of a probe has been of practical value in such cases.

CLAVICLE

Gunshot fractures of the clavicle are only serious on account of their complications, the chief of which are injuries to the lungs, brachial plexus, and subclavian vessels.

On account of the wounds it is often impossible to apply any of the typical bandages or apparatus, but otherwise their treatment in no way differs from that of the ordinary fractures met in civil practice.

GUNSHOT FRACTURES OF THE HUMERUS

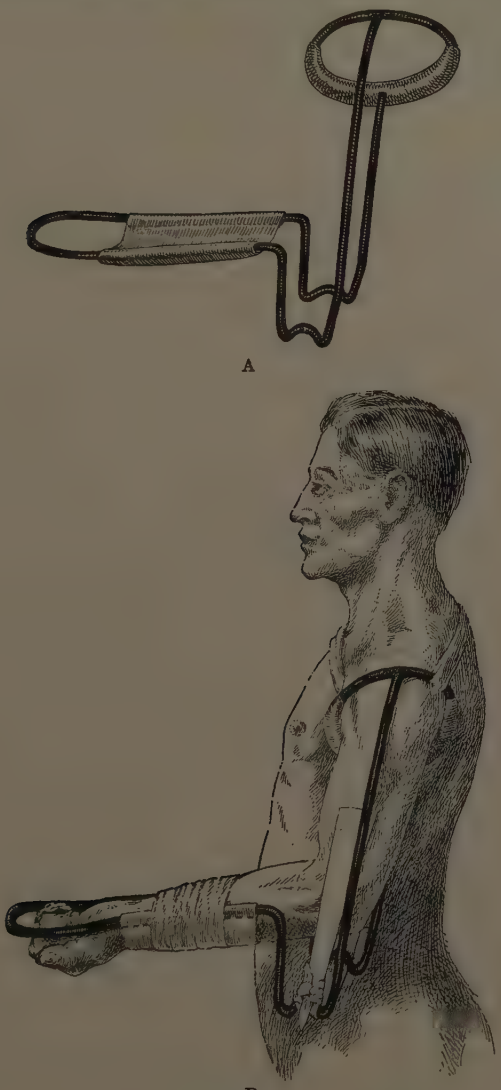
These fractures comprised 3651 out of 15,165 fractures of the long bones admitted to American Military Hospitals in 1918,* this number including all fractures, whether complicated by fractures of other bones or not.

Most persons with fractures of the humerus are able to walk from the field. Although traction should be applied in the field, in the absence of splints for this purpose the arm may be fairly satisfactorily immobilized by means of the sling and body bandage, taking care that there is sufficient padding at the side of the chest to prevent incurvation. The field splint for the transportation of these fractures, recom-

* From records of admissions to hospitals compiled by Colonel John B. Walker, M. C.

mended by the Splint Board, is the Murray hinged modification of the Thomas arm splint (see Figs. 161, 162).

As most of these patients are evacuated at once after operation at the evacuation hospital, the same splint may be used until they reach



A

B

FIG. 173.—A, THE JONES TRACTION HUMERUS SPLINT. B, THIS SPLINT IS MADE IN RIGHTS AND LEFTS, AND IS APPLICABLE TO THE AMBULATORY TREATMENT OF FRACTURES OF THE HUMERUS NOT REQUIRING A POSITION OF ABDUCTION AND TO SOME FRACTURES OF THE FOREARM. TRACTION MAY ALSO BE MADE BY A HITCH ABOUT THE PADDED ELBOW.

the base. The ordinary Thomas splint is impractical for stretcher transportation, and the Jones splint (Fig. 173) offers no advantage over the Murray splint.

Fractures of the humerus are not infrequently accompanied by injuries to the musculospiral nerve and sometimes by injuries to the other great nerves. Therefore, when symptoms of injury to any of these nerves are present, these should be carefully exposed at operation, and if the operation is done before infection has become established the nerves should be sutured, if necessary. In any case a careful note should be made of the extent of injury to any of these nerves, particularly if paralysis is present. This is important for two reasons: one being that the musculospiral nerve may be paralyzed by inclusion in the callus, a condition demanding immediate operation; the other reason being that the nerves are often temporarily paralyzed by contusion without solution of continuity of the nerve-fibers.

In the definitive treatment at the base hospital the question arises whether it is better to put the patient to bed or to allow him to be an ambulatory case. In most of these injuries it is a distinct advantage for the patient to be in bed at least until the period of infection is past. Such being the case, and if the patient does not have to be evacuated before his fracture is united, the suspension treatment in bed is by far the best. If the patient has to be evacuated, either the hinged Murray splint (Fig. 161) or the Jones splint (Fig. 173) may be used.

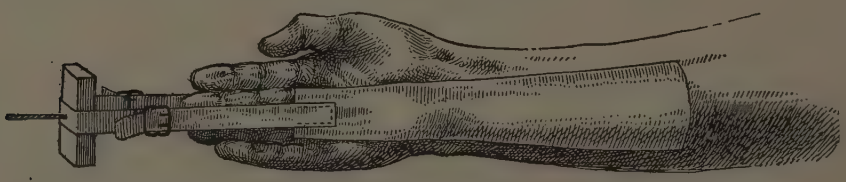
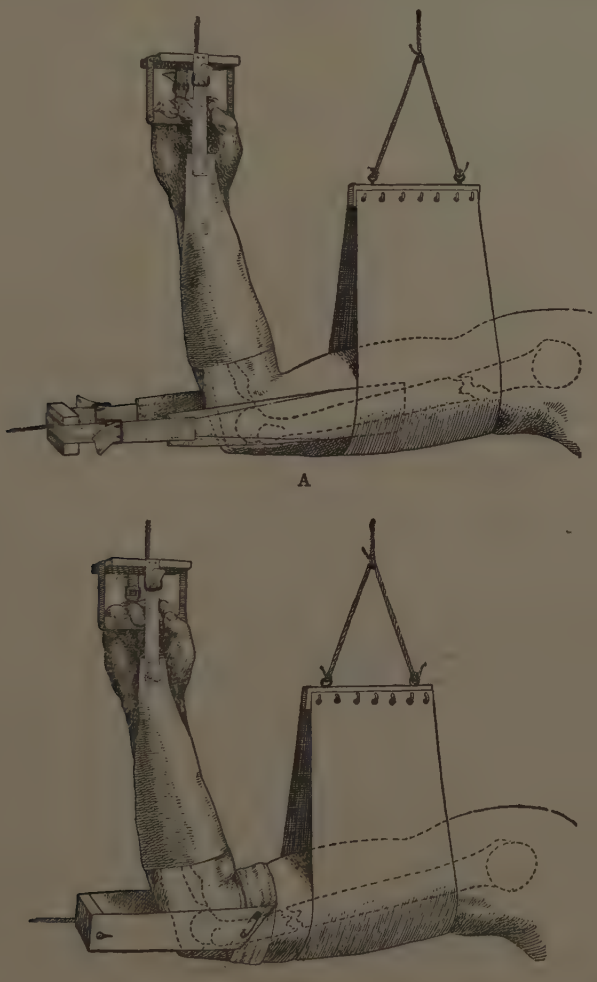


Fig. 174.—Method of Attaching Glued Bands to Forearm for Traction or Suspension. Tape is sewed to the bands, which may be made of Canton flannel or several thicknesses of gauze.

The suspension treatment has been particularly successful in the treatment of fractures of the humerus, and, from experience obtained by its use in comparison with other methods, it is probably safe to say that the period of treatment is lessened by at least one-third if not by one-half. To obtain all the benefits of the suspension treatment it should be carried out without any splints whatever. The splints, such as the Thomas splint, have the great disadvantage of fixing the articulations, thereby preventing one of the chief benefits obtained by suspension treatment.

The typical suspension treatment is carried out on the following principles: The weight of the forearm is counterbalanced by a weight attached to a cord, which in turn is attached to the forearm by glued bands by the method shown in Fig. 174. The weight of the upper arm is likewise counterbalanced by a weight attached to a sling of non-absorbent material, such as rubber sheeting, which passes under the arm and is easily removable to permit dressings. Angular deviation and overlapping are overcome by traction applied to the arm by one of the methods shown in Fig. 175 and made in the direction of the position occupied by the upper fragment when at rest. The line of trac-

tion, therefore, varies according to the site of fracture. In low fractures in which there is no tendency to abduction of the upper fragment, traction may be made straight to the foot of the bed, while for the higher



A

B

FIG. 175.—DETAIL OF METHOD OF SUSPENSION AND TRACTION FOR FRACTURE OF THE HUMERUS.

Suspension of forearm is made by bands glued to skin and which are attached by straps and buckles to a wooden spreader. A round wooden handle is attached by pieces of elastic webbing to ends of spreader, thus enabling patient to exercise the fingers. The arm is suspended by a sling of rubber sheeting, one end of which is tacked to one side of a wooden spreader; the other end is pierced with eyelets which hook over hooks on the other side of the spreader, so that the sling can be reduced for dressings. Traction in case of high fracture (A) is made by bands glued to the skin of the arm and attached by buckles and straps to a wooden spreader. In low fractures (B) by doubled band of muslin 6 cm. wide fastened as shown about the padded arm just above the elbow. The padding under the band has been omitted in the drawing for the sake of clearness. In practice the Dakin pad over the wound suffices. Screw heads on the ends of the spreader button into holes in the ends of the band.

fractures the line of traction is shifted by means of the abduction board illustrated in Figs. 176 and 177. In some fractures in the region of the surgical neck the abduction and rotation outward of the upper frag-

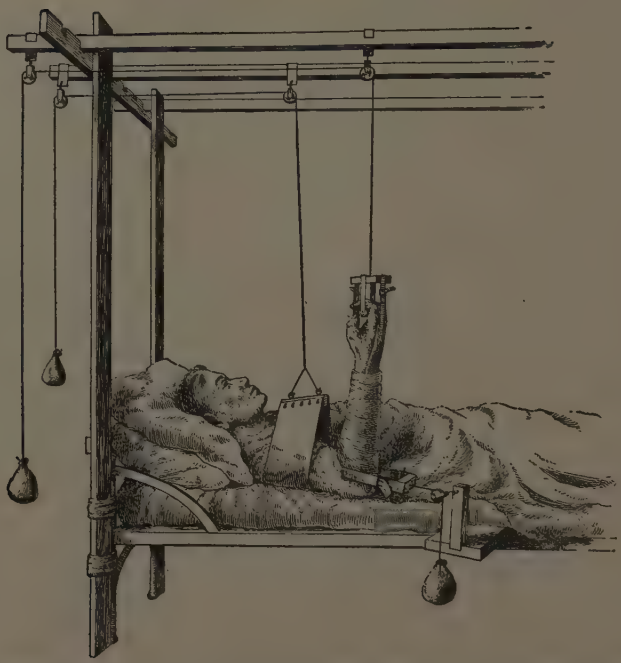


FIG. 176.—METHOD OF INSTALLING TRACTION WITH SUSPENSION FOR FRACTURES OF THE HUMERUS.

In this instance traction is made by bands glued to the arm and buckled to a spreader. The pulley for the traction cord is attached to the abduction board; the amount of abduction being adjusted by slipping the board in or out under the mattress. Note the arrangement for suspension, the hand and forearm being suspended in a plane lateral to that in which the arm is suspended. For details of improved abduction board see Fig. 177.

FIG. 177.—IMPROVED ABDUCTION BOARD FOR TREATMENT OF FRACTURES OF THE HUMERUS.

The long horizontal member is placed transversely under the mattress. The vertical member is adjustable angularly with the horizontal member by means of the bolt and wing nut connecting them. The pulley for the traction cord is mounted on a cross-piece which can be raised or lowered on the vertical member so as to correspond with the level of the humerus. See Fig. 176. (By courtesy of Dr. Kenneth Bulkley.)

ment may be so great that traction on the arm may have to be directed above the head of the patient, as illustrated in Fig. 178. This exaggerated position of abduction has given perfect results in these cases of higher fracture, and as this position is not obtainable by any ambulatory splint, the superiority of the bed treatment is evident.

As soon as the arm has been supended radiographs are taken for the purpose of determining whether the adjustment of the suspension and traction weights is correct, and then they are changed and shifted, if necessary, to meet the indications, radiographs being taken after each change is made. The average weights for suspension and traction are

FIG. 178.—METHOD OF TREATING FRACTURES OF THE SURGICAL NECK OF THE HUMERUS. Note the marked abduction and rotation out necessary to bring the distal in line with the proximal fragment.

about 3 pounds (1500 grams) each, but these have to be varied according to the musculature of the arm and to the position of the fracture. For example, in fractures at the middle of the bone there may be a tendency to backward angulation. If so, the suspension weight on the arm should be increased and that on the forearm diminished. In fractures at the distal part of the humerus there is a tendency to flexion of the lower fragment at the elbow (Fig. 179) and this is combated by increasing the weight suspending the forearm, diminishing that suspending the arm, and shifting the point of suspension of the forearm toward the head of the patient.

It will be noted that the forearm and the upper arm are suspended from separate longitudinal bars. This is done for the reason that when the arm is suspended in a position of abduction the point of suspension of the forearm and hand is lateral to that of the arm. If they are both suspended from the same longitudinal bar it has been found that there is a tendency to outward curvation at the point of fracture.

Traction is best applied by bands glued to the arm below the site of fracture, but in the great majority of gunshot fractures the wounds interfere with placing of the glued bands. In such cases satisfactory traction can be made by means of a double muslin band about 6 cm. wide, which is passed in sort of a figure-8 manner about the arm just above the elbow, the middle of the band being laid against the back of the arm, and the ends of the band being attached to a spreader to prevent pressure upon the epicondyles. In order to bring the traction in line with the arm the ends of the band as they leave the arm are caught by pins to the encircling part (Fig. 175, B). In all cases the elbow must be carefully padded to avoid pressure and constriction by the

FIG. 179.—TRACING OF RADIOGRAPH IN THE ARMY MEDICAL MUSEUM OF COMMINUTED GUNSHOT FRACTURE OF LOWER PART OF HUMERUS, SHOWING USUAL DEFORMITY IN SPITE OF FLEXION OF THE ELBOW.

band. In wounds of the lower part of the arm the pad used for the Carrel-Dakin dressing answers for this purpose. When dressing these wounds an assistant should support the forearm and elbow and, at the same time, make slight traction. The sling under the arm is then unhooked and the dressing proceeded with.

It should be emphasized that the suspension and traction method is a method for conserving the mobility of the articulations. No fixation in the ordinary sense is employed, traction being made in the direction of the axis of the proximal fragment, when that fragment is in the position of physiologic rest. Applied thus considerable latitude of motion of the contiguous articulations is possible without producing motion at the point of fracture. The patient may move about in bed at will and even sit up in a chair at the side of the bed. He can move his fractured member up and down, and he should be encouraged to move his shoulder and elbow gently from the very start. As stiffening progresses at the point of fracture, the elbow and shoulder are moved more and more freely. Active motion is the best, the patient loosening

the weight on his forearm with the well hand, thus allowing free play at the elbow. Massage and very gentle passive motions are begun early to the shoulder, elbow, and hand, and later massage should be extended to the whole arm. When union is completed it will be found that the patient has full and normal control of the member. It is a mistake to let the patient up too soon with a sling, as it will be found that unless he is made to take the arm from the sling several times a day and move it, stiffening of the joints will occur. In this connection it may be stated that suspension has given some of the best results in complete excisions of the elbow.

In case of paralysis of the musculospiral nerve a cock-up splint should be worn (Fig. 180). This should be put on immediately and

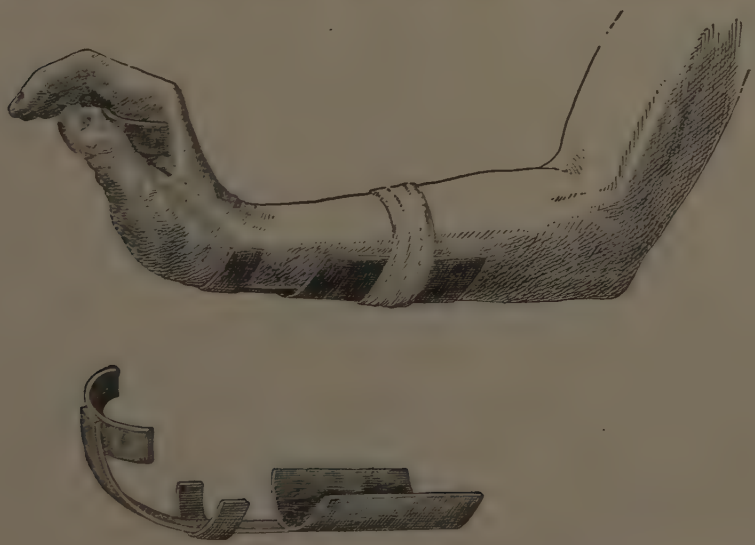


FIG. 180.—JONES' COCK-UP SPLINT FOR DROP-WRIST.

This splint, at least in the early stages of musculospiral paralysis, should be supplemented by splinting to prevent flexion of the fingers. It is applicable to the treatment of some fractures of the carpus and metacarpals if the transverse palmar piece is replaced by a hemisphere, with its convexity toward the palm.

should not be removed until the extensor muscles have regained their power, as otherwise they may be overlengthened.

When it is impossible to keep the patient in bed, some form of ambulatory splint has to be applied. The Jones humerus traction splint (Fig. 173) is an excellent splint for fractures of the middle and lower third of the humerus, but is unsuitable for cases in which abduction is necessary. Abduction may be obtained by the use of the abduction arm splint described in the Manual of Splints and Appliances, or by an abduction splint made of plaster of Paris with reinforcement, but none of the abduction ambulatory splints afford the rotation outward which is necessary to meet the strong external rotation of the upper fragment present in some cases. Abduction may also be obtained by using the

Thomas or Murray hinged splint by supporting it by another splint which bears against the pelvis. But this method has the serious disadvantage of keeping the elbow in the extended position. A number of very ingenious ambulatory splints were used during the war, among which may be mentioned the Borchgrevink, Alquier, Delbet, and Leclerc splints. Most of these splints have been devised to produce traction by means of adjustable spiral springs in the stem of the splint, traction being made by pressure on the flexed forearm just below the elbow and countertraction at the axilla.

Care should be taken in the use of all apparatus to prevent ulceration of the skin, both from pressure of the splints and from contact of the arm with the side. Absolute cleanliness and sufficient padding are indispensable.

GUNSHOT FRACTURES OF THE FOREARM

Of a total of 15,165 fractures admitted to American Military Hospitals in 1918* there were a total of 2070 fractures of the forearm. Of these, 1246 were of the ulna alone or associated with fractures of bones other than the radius, and 63 fractures of the radius alone or associated with fractures of bones other than the ulna, and 761 of the radius and ulna.

Gunshot fractures of the forearm are extremely difficult to treat. On account of the usual comminution and projection of splinters of bone into the tissues cross-union or interference of callus is apt to occur, and on account of the numerous muscles and tendons it is extremely difficult to secure adequate drainage in case of infection, which may lead to serious loss of function from sloughing of tendons and from cicatricial fusions. Moreover, it is difficult to retain the fragments in proper position, and on account of the contracture of the muscles there is a marked tendency to overriding of the fragments as well as to anterior, posterior, and lateral angulation.

Normally the bones are of equal length, with an outward curve to the radius. In the movements of pronation and supination the head of the radius rotates in its socket, while the distal end makes a circumferential movement about the end of the ulna, the axis of rotation of the forearm being in a line from the head of the radius to the lower end of the ulna. To conserve these movements it is important to preserve the equality of length of the bones and the radial curve and to prevent rotation of the radial fragments on one another. In fractures of the ulna alone there is little tendency to rotary deformity, but in fractures of the radius, either associated with or without fracture of the ulna, the upper fragment is rotated outward, *i. e.*, supinated by the biceps, and the lower fragment rotated inward, *i. e.*, pronated by the action of the pronator quadratus and of the pronator radii teres if its attachment is preserved. Consequently, it is necessary in all fractures of the radius to place the hand in the position of complete supination so as to have

* From records of admission to hospitals compiled by Colonel John B. Walker, M. C.

the lower fragment meet, in so far as possible, the position occupied by the upper.

The proper operative treatment of fractures of the forearm is extremely important, as the loss of the use of a hand is much more serious than that of any other member. They should, therefore, be operated upon at as early a moment as possible and the technic of the operation should be most minutely and carefully carried out. All shredded and contaminated tissues should be carefully removed, the tendons and nerves should be repaired, and it is better on account of the tightness of the deep fascia not to close the wounds completely even if primary union is attempted.

FIG. 181.—METHOD OF USING THOMAS TRACTION ARM SPLINT FOR THE AMBULATORY TREATMENT OF FRACTURES OF THE FOREARM.

For sake of clearness the bars of the splint have been drawn straight, but in practice it is better to separate them opposite to the hand. The splint is supported by slings in the conventional manner and not exactly as depicted, as the sling passes on the outside of the splint and supporting bands. Counter-traction is furnished by the bands about the splint and arm, and traction as shown by the Spanish windlass or by elastics.

Drainage by rubber tubes should never be employed on account of the danger of necrosis from pressure. If there is opportunity for perfectly aseptic technic, even rifle-ball wounds with punctate orifices should be operated upon in order to remove spcules of bone which might interfere with function and to repair muscles and tendons.

Although traction is important in the treatment of these fractures, it is extremely difficult to apply it satisfactorily in the field unless the fracture is high and adhesive straps can be applied. As has already been stated, hitches should not be taken around the wrist, as they are apt to be left on too long, with disastrous consequences.

In cases which can be handled without traction the forearm and arm can be bandaged to a bent wire ladder splint with the hand in supina-

tion. The splint, therefore, should extend from the head of the metacarpals on the back of the hand to above the elbow, so as to prevent rotation of the forearm. For bad injuries of the upper part of the forearm in which adhesive strips can be fastened to the lower forearm and to the hand, it is best to use the Thomas hinged arm splint, thus providing traction. This can be applied in the manner shown in Fig. 181.

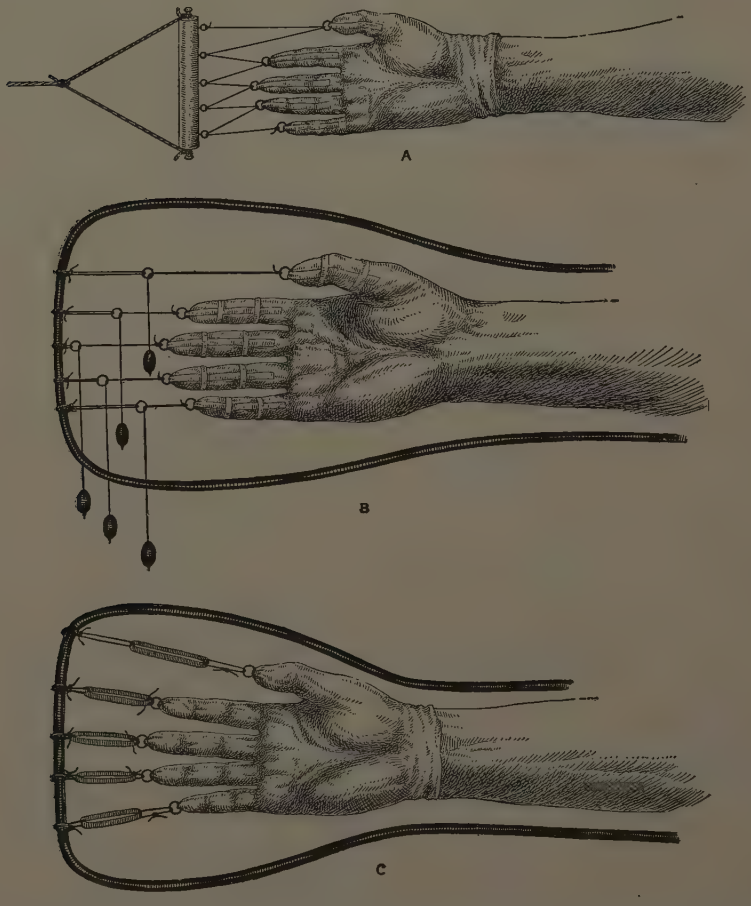


FIG. 182.—METHODS OF ATTACHING TRACTION TO THE HANDS AND FINGERS.

A, Cotton glove glued to hand. Curtain rings sewed to fingers of glove by means of tape. Traction made by laced cord, thus equalizing traction on the digits. B, Curtain rings attached to digits by strips of adhesive. Traction by individual weights, thus permitting greater latitude of movements of individual digits and exact determination of the amount of traction. C, Cotton glove glued to hand. Curtain rings sewed to tips of fingers of glove. Traction by rubber elastics. This method is inferior to A as regards attachment of traction and to B as regards application of traction.

After operation this splint may be continued, but the bars of the splint opposite the hand should be pulled apart in order to give room for the hand. A better splint is the one shown in Fig. 182, *B*, *C*, which provides ample room for the hand and a means of producing traction either by a glove glued to all the hand or by strips attached to each finger.

With these splints the traction can be made either by elastic bands or by individual weights attached to each finger (Fig. 182, *B*). The system of using individual weights permits of a little more freedom of movement of the fingers, thus conserving the functions of the tendons. Either of these splints may be combined with suspension, which is particularly advantageous in the early stages of the treatment. After infection has subsided and the condition of the wound permits it, the Van der Veld or Sinclair splint may be used (Fig. 183). These splints are especially valuable for maintaining a position of supination. In

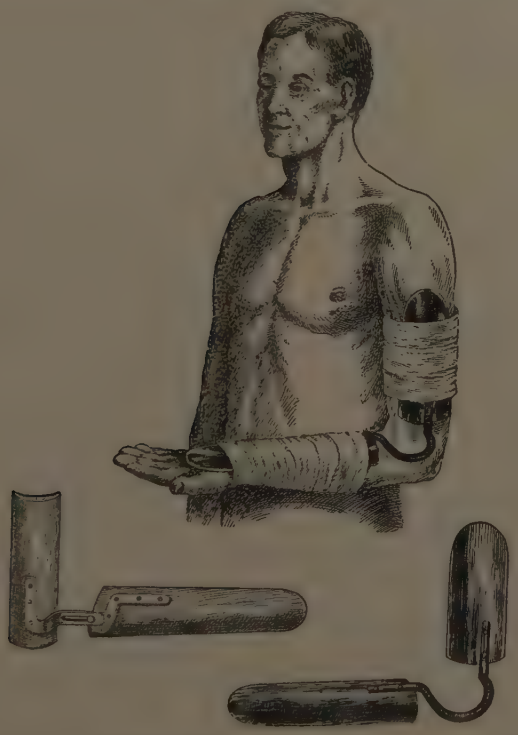


FIG. 183.—APPLICATION OF THE VAN DER VELD AND SINCLAIR SPLINTS FOR FRACTURES OF THE FOREARM.

It will be observed that these splints are alike in principle in preventing pronation through the placing of the arm piece on the outer aspect of the arm. The Sinclair splint is made of metal, the Van der Veld of wood, and the latter has a slot and bolt permitting adjustment in angle and length.

cases in which there are no wounds or the wounds are closed, a molded plaster-of-Paris splint is very satisfactory. This should be arranged to come up on the back and outer side of the arm above the elbow in order to prevent pronation.

The principles recommended by Willems for the treatment of injuries of the joints should be applied to all injuries of the forearm; that is, active motion should be continuously carried on throughout the treatment. For this reason splints should be arranged to be removed several times a day if necessary. If these movements are not carried

out, adhesions are apt to form in the tendon sheaths, and the functions of the hands and fingers may be lost or irreparably damaged.

In fractures of a single bone traction is not so important as in fractures of both bones. In some cases, however, there is a tendency to lateral deformity with overlapping, and these are best treated by traction, particularly in the first stages. Fractures of the ulna may be placed in a position midway between supination and pronation. All fractures of the radius, whether alone or with the ulna, should be treated in a position of complete supination.

FRACTURES OF THE METACARPUS AND PHALANGES

Gunshot fractures of the metacarpus and phalanges are usually accompanied by loss of substance, which, in the case of the phalanges, generally demands amputation. In treating fractures of the metacarpus the natural curves of the hand should be preserved. These are two, one in longitudinal direction corresponding to the curvature of the metacarpal bones, and the other a transverse curve corresponding to the transverse arch of the hand. As both of these curves have their concavity directed toward the palm of the hand, they can be conserved in treatment by bandaging the hand over a convex support. An excellent one for this purpose is a rubber ball about the size of a tennis ball. This, when using a cock-up splint, may be supported in a concavity formed in the palmar portion of the splint. A splint thus arranged is efficient, as it not only preserves the curvatures referred to but also prevents the extensor tendons from becoming overstretched, and at the same time permits of active motions of the fingers. Occasionally traction is of benefit in treating these fractures, and in such cases traction may be made to individual digits and their corresponding metacarpals by using one of the splints recommended for fractures of the forearm (Fig. 182).

As the great danger of wounds of the hand lies in the extension of infection to other structures than those immediately involved, the question of early and complete operation is important. In fractures of the metacarpals, especially if the tendons of the corresponding digit are destroyed, it is often wise to form a complete excision of the metacarpal with its digit and resort to primary suture if possible. These operations have been extremely successful in avoiding infection and in conserving the function of the hand.

GUNSHOT FRACTURES OF THE FEMUR

Gunshot fractures of the femur comprised more than one-fifth of the fractures of the long bones, 3401 of a total of 15,165 admitted to American Military Hospitals in 1918.* They are among the severest of war injuries. The primary mortality from shock and hemorrhage is high, many succumbing on the battlefield. An estimate of 40 per cent. is probably not far afield. For those who reach the hospital gas gangrene

* From records of admissions to hospitals compiled by Colonel John B. Walker, M. C.

is an early danger and, later, streptococcus sepsis, and 20 per cent. is probably a conservative estimate of the mortality from these two latter causes. The morbidity from chronic osteomyelitis as well as the crippling from amputations, made necessary by extensive destruction of tissue and by infection, add still more to the seriousness of this wound, the treatment of which, therefore, occupies a place of primary importance.

The limb should be immobilized with traction at the earliest possible moment by use of the Thomas splint (see p. 452). There is nothing more striking to the advanced area surgeon than the relief experienced by patients with fractured femur after the application of this splint. If the position of the wound precludes the use of the Thomas splint, the long Liston splint (Fig. 169) may be employed. Traction may be obtained by a hitch on the foot and countertraction by passing a loop from the axillary end of the splint between the thighs. The splint of Pouliquen, a combination of the Liston and Delorme aluminum gutter splint used in the French Army, is a superior device permitting comfortable immobilization and traction.

Arrived at the hospital the question of operation is decided, and, if necessary, resolves itself into that of amputation or épluchage.*

As the function of the lower extremity is essentially that of weight bearing, unless there is hope of retaining a strong limb it is wiser to amputate than to run the risk of a prolonged and often stormy convalescence. Consequently, the surgeon should not take chances in fractures of the thigh that would be perfectly justifiable in fractures of the upper extremity, the preservation of the slightest portion of which is of value.

The indications for amputation may be divided into two groups: The first, for immediate amputation; the second, for amputation after infection has become established. Immediate amputation should be done for: (1) Extensive loss of groups of muscles, especially if the sciatic nerve is severed; (2) division of both femoral and internal saphenous veins; (3) excessive comminution of the greater portion of the shaft—20 cm. or more; (4) shock, when it is deemed that the patient will not survive the primary épluchage, since amputation is shorter and less shocking and the convalescence quicker. The indications for amputation in the case of established infection are: (1) Injury to the femoral artery or vein requiring ligation, (2) gas gangrene when more than one group of muscles is extensively involved, (3) extensive fracture of the diaphysis communicating with the knee-joint when the latter is also suppurating, (4) multiple wounds threatening life, (5) incurable chronic osteomyelitis. The drifting policy should not be followed in septic cases; amputation should be done before visceral degeneration takes place.

* Épluchage, literally translated, means "paring," as generally applied to the preparation of vegetables, and is used exclusively by French surgeons to describe the latest treatment of wounds as practised by Le Maitre and others. It is preferable to the word "débridement," which simply means opening and drainage, and which was used early in the war to describe the first operations practised.

The primary operative épluchage is long and severe, and the patient must have recovered from shock before it is undertaken. Nitrous-oxid-oxygen anesthesia should be used. The wounds should be enlarged so as to obtain free access to their deepest parts—transverse incisions should be avoided if possible. Flexion of the thigh on the pelvis relaxes the muscles and facilitates retraction. The danger of infection is largely due to extensive destruction of muscles, and consequently great care must be taken to remove all devitalized tissue. Greater attention than usual should be paid to the perfection of hemostasis on account of the depth of the wounds and the consequent danger of retention of blood.

Dependent counterdrainage should be provided in all operated fractures. The drainage incision should be made at the outer border of the biceps and should extend to above the site of fracture, so as to avoid pocketing when the thigh is flexed.

Immediate suture of the wounds is not to be recommended except in selected cases and when perfect technic is possible. They should usually be left for delayed primary or secondary suture.

Immobilization and traction are the principles in general to be adopted for treatment at the base hospital. However, in the light of experience with suspension and traction, it seems better to modify the concept of immobilization to that of maintenance of the distal fragment in proper alinement with the proximal by sufficient corrective external forces, including the straightening effect of the muscular envelope produced by traction. Under this concept, the fractured thigh as suspended is not immobilized, as the hip and knee-joints may be and are moved, but the fragments remain in alinement; such slight motion between them as may occur in no way retards union and, moreover, prevents the stiffness or ankylosis of the joints which is so common after the use of the older methods.

"Reduction by traction in fractures of the diaphysis (of the femur) is the method of choice always on condition that it be combined with early movements of the articulations. All the efforts of the surgeons should be directed to avoid ankylosis or stiffness of the knee, they appearing still too often in the end-results."*

Suspension and traction at the end of the war had come to be widely recognized as the method of choice in the treatment of compound fractures of the femur. To this end the full ring Thomas splint is the most widely useful. If the half-ring modification is used, the half-ring should be fixed, as otherwise the ring tends to flatten out underneath the buttock instead of remaining in position against the tuberosity of the ischium. Where the position of the wound forbids the use of the Thomas splint, the Hodgen (Fig. 184) can be substituted or the half-ring Thomas splint used upside down. The Hodgen does not afford as good control of the limb. The limb rests on slings of wide flannel bandage pinned to the bars of the splint. Three bridles of rope for suspending are ordinarily used (Figs. 184, 185). One is at the upper end

* Conclusions Conférence Chirurgicale Interalliés, VI Session, p. 3.

of the splint, to which a rope carried over a pulley at the head of the bed is attached. This, when using the Hodgen, serves to keep the splint up against the thigh, and when using the Thomas helps to prevent the rings slipping over the ischium (see p. 491). Of the other two, one is placed preferably just above the knee and the other at the malleoli. The rope attached to them is carried through pulleys on an

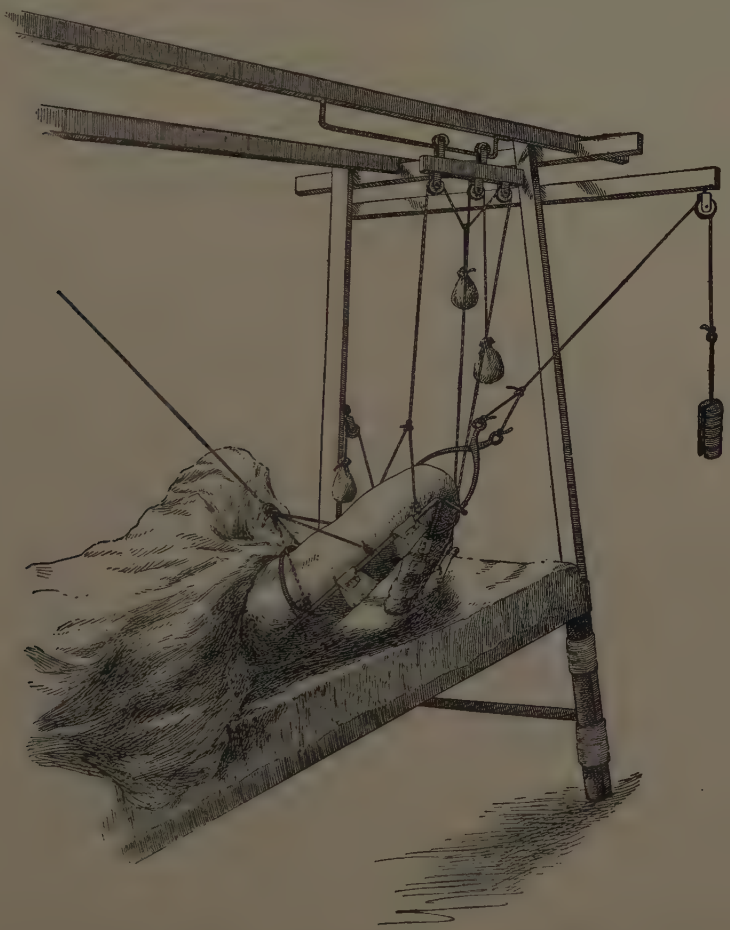


FIG. 184.—ILLUSTRATING THE METHOD OF OBTAINING ABDUCTION AND OUTWARD ROTATION IN TREATING HIGH FRACTURES OF THE FEMUR WITH THE RANSOHOFF TONGS.

In this case a Hodgen splint is used, although a bent Thomas is preferable if the wounds do not prevent its use. Note the direction of the traction, also the cord and weight attached to the lower end of the splint, which pulls the foot inward, thus rotating the lower fragment outward.

overhead trolley, with the counterbalancing weight hung between the pulleys.

To prevent drop-foot a flannel band is glued to the sole of the foot and attached to a weight through an overhead pulley (Fig. 186).

The splint should be bent about 5 cm. above the level of the knee-joint to allow flexion of the knee and at the same time let it drop below

the axis of the thigh, thus accentuating the upward support of the slings under the lower fragment. A better arrangement is the supplementary leg-piece devised by Pearson, which is attached to the main splint at a point above the level of the knee (Figs. 163, *A*; 185).

Two varieties of traction may be employed—skin or skeletal. The advantages of the latter are becoming appreciated, and it should be used more generally, especially in difficult cases.

Skin traction may be by means of moleskin, diachylon plaster, or bands glued with Sinclair's or Heussner's glue (see p. 497). The bands should extend from above the malleoli to just above the knee.

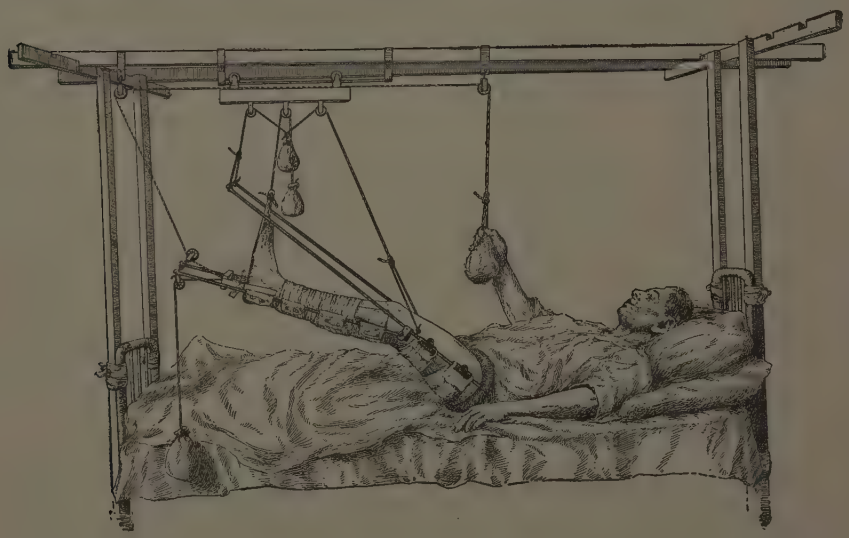


FIG. 185.—APPLICATION OF THE METHOD DEVISED BY DR. R. T. KNIGHT FOR MOBILIZING THE KNEE IN FRACTURES OF THE FEMUR WHEN USING SKIN TRACTION AND THE PEARSON ACCESSORY LEG PIECE.

The sum of the two weights should equal the traction desired. The weight in the hand plus the weight to overcome foot-drop should counterbalance the other traction weight and the weight of the leg. The patient carries out the motions himself. With skin traction thus applied the motions should not be commenced until there is beginning union. With skeletal traction applied by tongs directly to the distal fragment, traction is made in the line of the main splint by a cord passing over a pulley on a cross-piece on the suspension frame and there is only need of the weight passing to the hand which, together with the drop-foot weight should counterbalance the weight of the leg. Motion with the tongs may be instituted before union has commenced.

Traction may be applied by the Spanish windlass method to the end of the splint, as described for transportation (intrinsic traction), or by a weight over a pulley (extrinsic traction). In the former case the patient has to bear the discomfort of the entire force of traction as countertraction against the tuberosity of the ischium, and very careful attention to the skin there is necessary to keep it from ulcerating. In addition, the amount of traction is always uncertain and requires constant readjustment. Traction by a weight acting through a cord running over a pulley is, therefore, preferable. When using the Thomas splint three methods of applying traction by weight and cord are available. In one the cord is attached directly to the spreader to which the traction bands are fastened (Fig. 185); in the second the cord is attached

to the end of the splint to which the spreader is also attached, thus providing a means of adjusting the splint on the limb through the buckles on the spreader. The third method, called the method of fractional countertraction, keeps the splint in position against the tuber ischii with a pressure amounting to one-half or one-quarter of the traction, depending upon the number of pulleys used (Fig. 186).

The amount of traction depends upon the musculature of the individual and account should be taken of destruction of muscle. The average initial traction weight for skin traction is 50 to 60 pounds (22

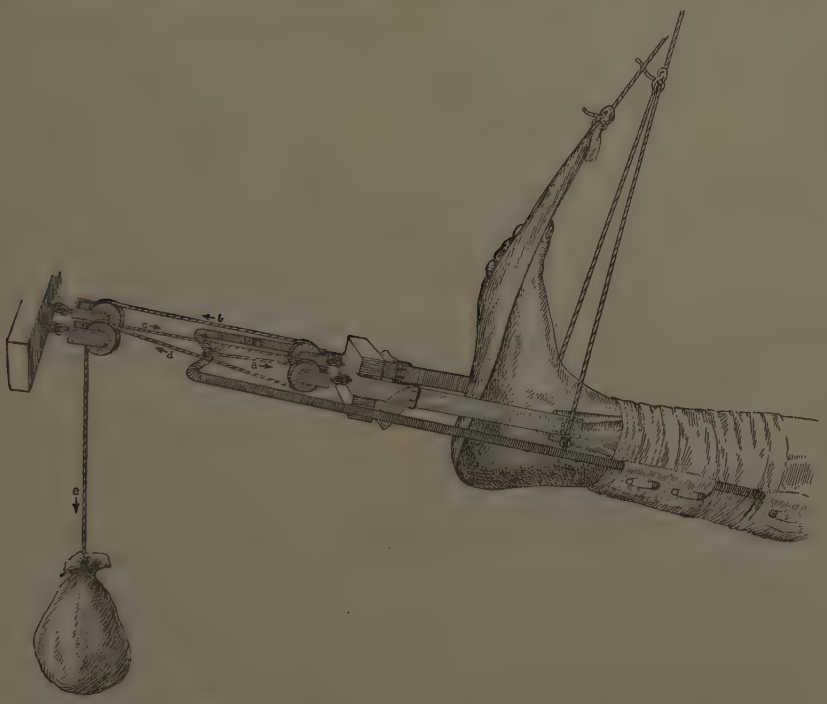


FIG. 186.—DETAILS OF METHOD OF INSTALLING FRACTIONAL TRACTION FOR FRACTURES OF THE LEG OR FEMUR IN ORDER TO DIMINISH THE UPWARD THRUST OF A THOMAS SPLINT AND YET OBTAIN ENOUGH TO KEEP THE SPLINT IN PLACE AGAINST THE ISCHIUM.

As drawn with four pulleys the upward thrust is one-fourth of the traction weight. With two pulleys it would be one-half. Observe also the position of the band glued to the sole of the foot to prevent foot-drop. It passes up along the inner border of the great toe, thus causing a slight outward rotation of the leg which is necessary in treating some fractures of the femur.

to 27 kilos), which should be reduced to one-half or less as soon as reduction is accomplished.

Skeletal traction may be obtained by the Ransohoff ice-tongs (Fig. 184), the Codavilla pin, or the Finochietto stirrup (Fig. 187). The latter is only needed in fracture of the femur when other forms of traction are prevented by wounds or general blistering of the skin. As it is applied to the os calcis it therefore pulls through both ankle- and knee-joints. The Codavilla pin may be applied through the head of the tibia or the condyles of the femur. The head of the tibia should

only be used in cases in which the position of the wound makes condylar application impossible, because with tibial traction the pull is through the knee-joint, thereby immobilizing and stretching it. Tongs are not suitable for application to the tibial head, but are superior to the pin for condylar application, as they only penetrate the bone a short distance, if at all, on each side instead of perforating it. One advantage of skeletal traction applied directly to the lower fragment is a better control of position. Another is that weight so applied is equivalent to about twice the amount when applied to the skin. Experience has shown that shortening can be overcome by direct skeletal traction even when repair is well advanced and at a stage when its correction would be out of the question by any other method. A third advantage is in the facility with which the knee-joint can be mobilized. No other method is its equal in this respect. Experience has proved that the tongs are ordinarily tolerated until union has commenced or until only

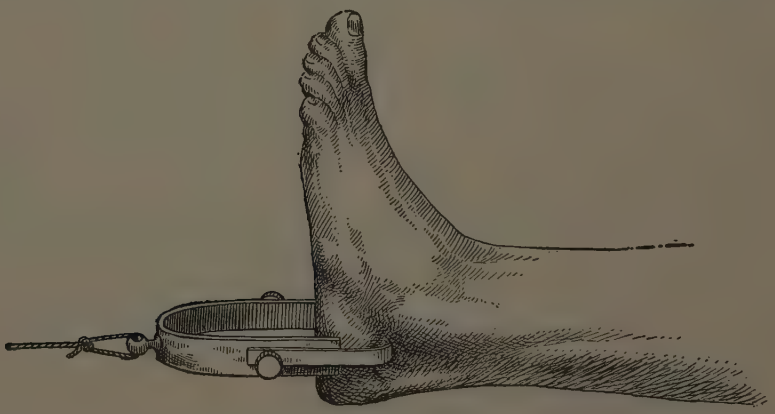


Fig. 187.—Finochietto Stirrup.
Showing its mode of application, the band passing just in front of the tuberosity of the os calcis.

a slight traction is required. Fear of infection of tong wounds has been found to be largely ungrounded.

If they have not been applied at the time of the primary operation, tongs or pin may be inserted with local or a brief general anesthesia given at the bedside. When either is to be used the skin is pulled upward and a longitudinal incision $\frac{1}{2}$ inch long is made in front of and just above the prominence of the condyle on either side.* It is then pulled upward gently and the tongs seated against the bone or the pin driven through. The tongs are held firmly until the traction is attached, otherwise they may fall out. It is well to place a block of wood between the handles.† This prevents the points being pressed into the bone. The usual cause of pain is dragging of the tongs or pin on the skin. It is to avoid this

* Pearson prefers applying the points to the shaft just above the condyles.

† A number of modifications of the original simple ice-tongs have been devised to prevent the points entering too deeply. All of them are excellent, but the wooden block will be found sufficient.

that the skin is pulled upward when incised; and before the dressing is applied the surgeon should see to it that there is no drag on the skin incision. In case it is necessary it should be lengthened.

When the tongs are inserted as described the synovial membrane will not be injured, although the space is limited between the suprapatellar pouch in front and the upward reflections of the synovia below.

In case of tibial application the pin should be driven through the bone at right angles to the shaft and about 1 cm. posterior to the tubercle.

In using all forms of traction it is well to elevate the foot of the bed so that the patient's weight acts as a counter to the traction, and prevents his sliding toward the foot.

The best arrangement for active and passive motion of the knee is the hinged auxiliary leg piece (Fig. 163, *A*) which clamps on to the Thomas at or above the level of the knee, the leg being suspended in it. A counterbalancing weight is attached to its end by means of an overhead pulley; the cord to this weight may, with advantage, pass within reach of the patient's hand. The Thomas splint itself is held steady by its original suspension ropes. If there is no supplementary leg-piece available a Thomas hinged arm splint can be substituted by slipping the ring over the Thomas and lashing it just above the knee. In case there is tong traction, the patient can move his knee without more ado, aided, if necessary, by his hand on the rope running to the counterbalancing weight.

FIG. 188.—TRACING OF RADIOGRAPH IN THE ARMY MEDICAL MUSEUM OF FRACTURE OF THE FEMUR WITH COMMENCING CONSOLIDATION.

The deformity is a characteristic result of insufficient traction and lack of support beneath the site of fracture, such as is often obtained by using a straight Thomas splint and skin traction improperly supervised.

If there is skin traction the problem is not quite so simple, but can be met as follows: From the spreader of the traction bands two traction ropes are run through pulleys attached to the end of the auxiliary splint. One of them is carried overhead through pulleys to a weight, the other attached directly to a down-hanging weight. The sum of these two represents the desired traction. They should be so proportioned that the overhead weight counterbalances the lower weight plus the weight of the leg (Fig. 185).

A patient arriving at hospital with a compound fracture of the femur is first radiographed and then operated upon if necessary. He is then ready to be suspended in such position as the radiograph and clinical examination indicate.

The mechanical problem varies with the location of the fracture. Those through the central portion of the shaft are in general simpler than those of the upper and lower ends, and will, therefore, be considered first.

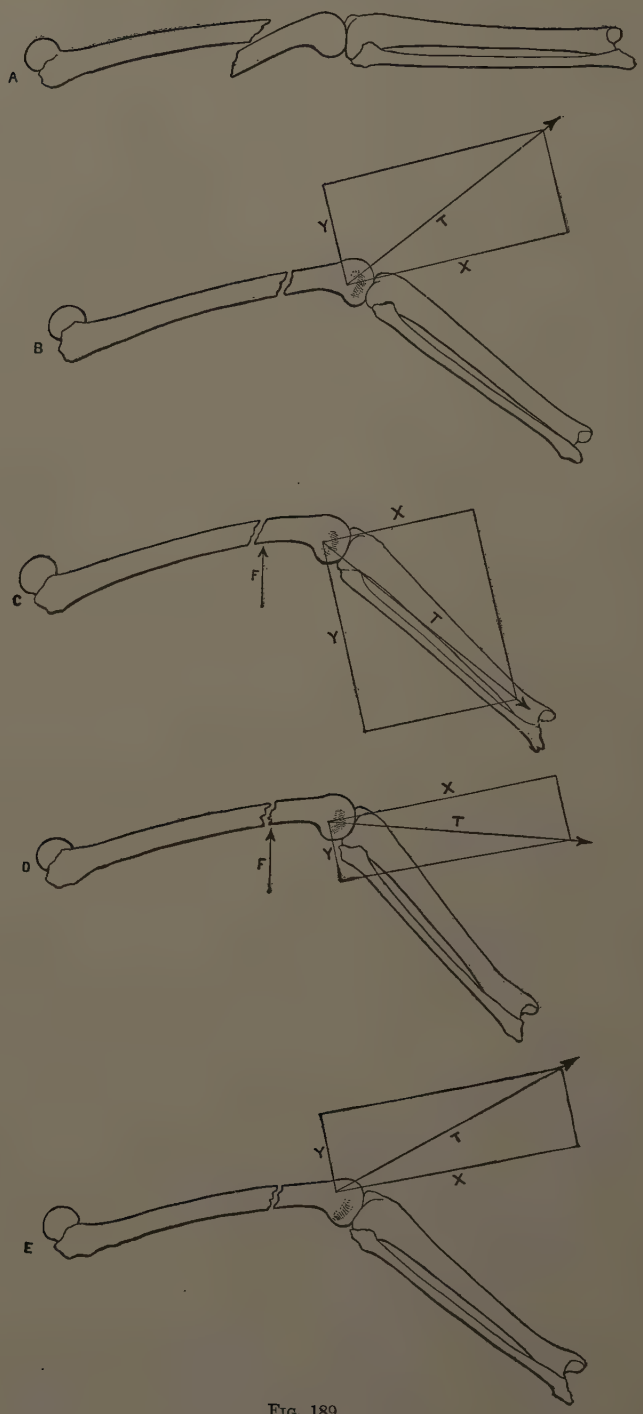


Fig. 189.

The femur normally has a slight anterior bow. In fractures even as high as the middle of the bone the distal fragment has a tendency to sag backward (Fig. 188). If union occurs in this position, walking strains the knee-joint and the foot is thrown forward, so that this deformity should be guarded against. Traction made in a line below the axis of the proximal fragment with the supporting slings drawn tight under the distal fragment combats this tendency (Fig. 189, *C*, *D*). If the posterior bowing still persists, a separate sling passed under the distal fragment and attached by a cord running over an overhead pulley to a weight of from 3 to 6 pounds aids the correction.

In fractures of the distal third of the femur the backward displacement of the distal fragment is marked and is due to the pull of the gastrocnemius (Fig. 189, *A*). It is not easy to correct. If tong traction is being used, the pull, instead of being in the axis of the proximal fragment, may be made higher, thus tilting the fragment forward (Fig. 189, *B*). With pin traction through the tibia or skin traction, the line of pull should be below the axis of the thigh, the knee being flexed about 30 degrees, thus pulling the distal fragment over the band supporting it and so prying it upward (Fig. 189, *C*). With the help of the auxiliary splint the amount of flexion of the knee can be readily varied until the right position is found. Van der Veld suggests introducing the tongs or pin well forward in the epiphysis so that traction will tend to roll the fragment *forward* into place (Fig. 189, *E*). If done, care should be taken to avoid the suprapatellar bursa. In addition to these measures, the supporting sling under the lower fragment (already described) will be found useful. In these low fractures it may be wiser to omit mobilization of the knee until some union has occurred.

In high fractures of the femur the tendency of the proximal fragment is to assume a position of abduction and external rotation (Fig. 190). The resulting deformity is difficult to overcome. The limb must

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FIG. 189.—THE USUAL DEFORMITY IN FRACTURES OF THE LOWER ONE-THIRD OF THE FEMUR AND THE DISPOSITION OF THE FORCES TO OVERCOME IT. IN THE DIAGRAM T = TRACTION; X = LENGTHENING FORCE; Y = LIFTING FORCE; S = SUPPORT OR FULCRUM.

A, Showing flexion of the distal fragment and overlapping. If not overcome the sharp end of this fragment may perforate the skin. B, Illustrating tong traction applied higher than usual to lower part of shaft just above condyles. Traction is made in an upward direction as compared with the axis of the proximal fragment. It is evident that the lifting component is increased and the lengthening component diminished when the point toward which traction is made is raised. In this case the points of the tongs are the fulcrum and the fragment is tilted into position by the weight of the leg and foot depressing the condyles. In practice the line of traction should at first be made to coincide with the axis of the proximal fragment and, as soon as overlapping is reduced, raised to increase Y and overcome the angular or vertical deformity. C, Illustrating skin traction and also tong and pin traction when applied to the tibia as well as stirrup traction to the os calcis. Traction in this case is always in the axis of the tibia and is transmitted to the distal fragment of the femur through the lateral ligaments of the knee and therefore the site of its application corresponds to their attachment to the condyles. As before, the traction force may be divided into two components, a lengthening X and in this case a depressing Y, which vary with the degree of flexion of the knee. To offset Y the supporting bands are kept tight under the distal fragment and constitute the fulcrum F. In practice, traction at the outset should be made with the leg almost extended until the overlapping is overcome, when the leg should be flexed until the vertical displacement is reduced. D, Illustrating tong traction applied to the distal fragment, but instead of the principle described in B, that described in C is utilized; namely, that of making traction in a line below the extension of the axis of the proximal fragment. It differs from C in that the degree of flexion of the leg has no influence upon the position of the distal fragment. Therefore by this method the greatest freedom of motion of the knee is permissible. E, Illustrating the method proposed by Van der Veld. The tongs are placed as far forward as possible on the distal fragment, and traction is made in or above the axis of the proximal fragment. The articular surface of the tibia being held opposed to that of the femur by the fascia lata and muscles of the thigh as well as perhaps to a certain extent by the attachment of the leg to the splint, a fulcrum is developed at the articular surface of the tibia and the forces may be resolved into one X, the lengthening force, and another Y tending to rotate the fragment upward.

be suspended in wide abduction. To obtain sufficient external rotation the splint should be tilted (Fig. 184). With the knee well flexed, as is easily practicable with tong traction, a light pull attached to the distal end of the splint, drawing it inward and upward, will throw the leg into marked external rotation. If, in spite of abduction, outward bowing at the site of the fracture exists, it may be corrected by sidewise traction. This is most easily accomplished by a sling holding the thigh snugly to the inner bar of the splint, which serves, in turn, for the attachment of the traction. As much as 20 pounds may be used for this purpose. Instead of lateral traction, when the wounds permit, Pearson's screw pads may be used*; one being attached to the outer bar of the splint and pressing inward against the proximal fragment, the other to the inner bar and pressing outward against the distal fragment.

FIG. 190.—TRACING OF A RADIOGRAPH IN THE ARMY MEDICAL MUSEUM OF A CONSOLIDATED GUNSHOT FRACTURE OF UPPER THIRD OF FEMUR SHOWING CHARACTERISTIC DEFORMITY RESULTING FROM INSUFFICIENT TRACTION, ABDUCTION, AND OUTWARD ROTATION OF LIMB. WEIGHT BEARING TENDS TO INCREASE THE OUTWARD BOWING UNTIL ANGULATION OF 90 DEGREES MAY ENSUE.

The leg suspended, the position should be carefully checked radiographically and subsequent pictures taken at intervals until solidification is complete. After dressings are done the supporting slings should be fastened up with care, else they may become slack, thus allowing backward dishing. Such details as the snugness of the bands require constant readjustment and the surgeon should give the apparatus painstaking oversight.

Massage may be given from the first. The knee may be mobilized actively and passively. The patient may later be taught to contract his thigh muscles gently, thus keeping them in better condition and improving circulation.

Sequestra must be watched for and removed as soon as separated. The operation requires wide exposure and careful handling to prevent stirring up infection.

The limb is suspended until union is firm. After the discontinuance of traction, bowing should be watched for, as not infrequently it will be found that the solidity of the union has been overestimated. When the consolidation has passed the test of removal of traction and the *x*-rays show the structural characteristics of firm bone, the patient may be allowed up on crutches and weight bearing gradually begun in those cases where the break has been of the transverse variety, particularly of the lower end of the bone. In high fractures and those where there

* A pad consisting of a piece of concave sheet metal padded with rubber sponge, which is fastened by a ball-and-socket joint to a screw which operates through a nut fastened to the bar of the splint.

has been extensive comminution and loss of bone, it is advisable to "caliper" the leg, thus allowing the patient to begin walking without bearing weight on the fracture. To this end a snug-fitting Thomas splint is applied. The bars are cut off at a sufficient length, so that 2 to 3 cm. of the end can be turned to a right angle at a level just below the level of holes made to receive them in the heel of the shoe. Both the heel and the sole of the opposite shoe may, with advantage, be built up about 1 cm. With this arrangement the weight is transmitted from the tuberosity of the ischium to the heel of the shoe and the patient walks without pressure on the fracture. It is important that the splint fit snugly. The large ring of the ordinary Thomas is not suitable to the average-sized thigh. For the purpose of calipering a number of different sizes of Thomas splints were supplied in the British Army. While the patient is about the calipers should be worn until union is firm.

As has already been stated, the consensus of opinion is that suspension and traction is the method of choice in the treatment of compound fractures of the femur. There are variations in the application of the method. For the sake of clearness I have presented first the method of suspension and traction as it has been carried out in my own service.

A practice which has been widely followed is to attach the end of the Thomas splint to the frame at the foot of the bed. The traction is made by fastening the traction bands to the end of the splint. They may be tightened by winding them up with a stick in the manner of the Spanish windlass. The foot of the bed is elevated and the weight of the patient's body serves as countertraction, relieving the pressure of the ring against the tuberosity of the ischium. The method has the merit of simplicity and excellent results may be obtained with it. It lacks the freedom of pulley suspension, the definiteness of weight traction, and the advantages of knee-joint mobilization.

The method of Lieut.-Col. M. G. Pearson, R. A. M. C., is simple and excellent. He uses a bed which consists of an ordinary tubular frame army (British) bedstead with the spring mattress removed and replaced by tight canvas slings, 11 inches wide, fastened by straps and buckles to one side bar of the bedstead, and by metal hooks or a quick release contrivance to the other. Upon the tight slings lies the mattress in three or more sections. In case of fractures of the femur one section lies immediately under the wound and is released for dressing purposes.

A movable arch of round iron resting on the side bars of the bed affords means of suspending the ring of the Thomas splint. This may also be accomplished by suspending with pulley and weight to an overhead bar. Suspension of the ring holds it snugly against the ischium and prevents its sliding over it. Pearson lays great stress upon it. The end of the splint is attached to the frame at the foot of the bed. Tongs are used with weight traction. An auxiliary hinged splint is attached to the Thomas splint in which the leg lies. The foot is suspended in a foot-piece on the auxiliary splint. It is hung by a chain and hook to the Thomas splint so that the amount of flexion of the knee is guided

at will. One overhead longitudinal bar only is used for suspension. Lateral bowing is not overcome by abducting the limb, but by using a screw and pad attached to the bar of the splint.

GUNSHOT FRACTURES OF THE TIBIA AND FIBULA

Of 15,165 fractures of the long bones admitted to American Military Hospitals in 1918,* there were 1607 fractures of both tibia and fibula, 2310 of the tibia, and 961 of the fibula.

A gunshot fracture of the leg is a serious wound, but much less so than that of the thigh. Not only are the bones smaller, but the muscular investiture is less. As a consequence primary shock and danger of gas bacillus infection are not so great, and the tendency to consider-

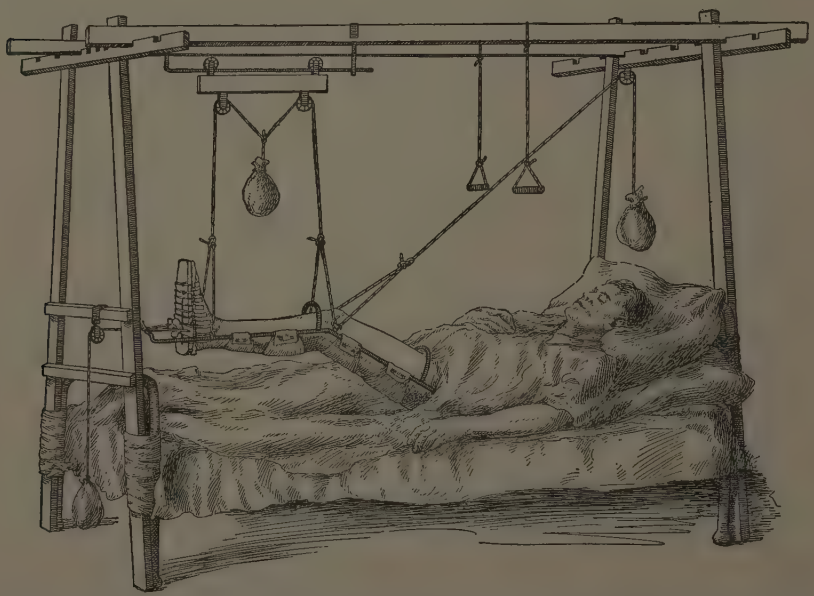


FIG. 191.—METHOD OF TREATING FRACTURES OF THE LEG USING THE HODGEN SPLINT AND THE SINCLAIR FOOT BOARD. THE HODGEN PERMITS MORE MOTION OF THE KNEE AND THIGH AND IS BETTER THAN THE THOMAS SPLINT WHEN TRANSPORTATION DOES NOT HAVE TO BE CONSIDERED. In order to illustrate the foot-board the foot has been drawn in a position of eversion, which is incorrect.

able overriding of the fragments is comparatively small. On the other hand, repair in the tibia is often very slow and separation of sequestra may be long delayed.

First-aid treatment should immobilize the fragments, with traction if possible. As for fractures of the femur, the Thomas thigh and leg splint serves admirably for this purpose as well as for the later treatment. For transportation it is important that a foot-piece be attached to which the foot is bandaged, else there will be rotary motion at the site of fracture and displacement. For fractures so low as to intefere with the application of traction the Cabot wire splint should be used. There are no special indications in regard to operative treatment except

* From records of admission to hospitals compiled by Colonel J. B. Walker, M. C.

that reduction should be accomplished at the primary operation. Injury of the posterior tibial vessels in the calf occasionally leads to a large deep hemorrhage associated with great pressure and danger of gangrene. This should be borne in mind and avoided by early intervention in suspicious cases. Primary suture of gunshot fractures of the tibia and fibula is much more often successful and far safer than in fractures of the femur.

For the definitive mechanical treatment suspension and traction is the best method. For this purpose a Thomas or Hodgen (Fig. 191) splint may be conveniently employed. The former for military purposes is the better. It has many advantages over the Hodgen if used with the supplementary leg-piece, in that it is more rigid and can be used to transport the patient to the *x*-ray or operating room or another hospital without change or disturbance of the leg, whereas the Hodgen is useless for transportation, as it does not provide intrinsic traction.

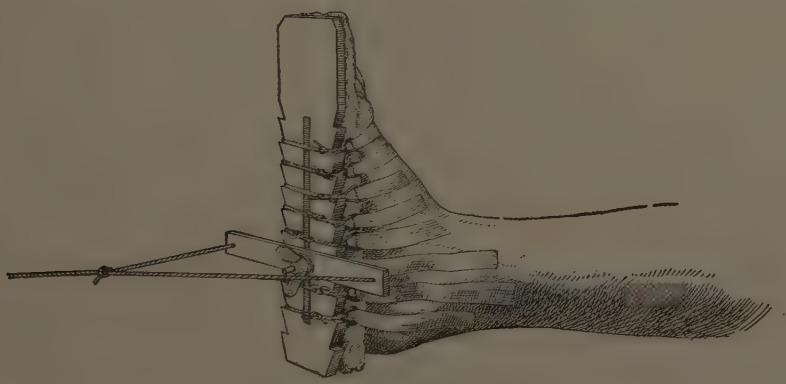


FIG. 192.—SINCLAIR FOOT-BOARD.

Strips, to which curtain rings bent into the shape of a triangle have been attached, are glued to the sides of the foot as shown and must not cross the dorsum. The padded board is attached to the foot by strings attached to the rings and tied under the board. (See Fig. 191.)

As fractures of the leg are treated with the knee in the flexed position, either the Thomas splint should be bent or, preferably, the supplementary hinged leg-piece should be used (Fig. 185). The angle should be about 135 degrees and at the level of the knee. The splint is suspended by three bridles. In order to provide countertraction a cord is led back from the upper bridle over a pulley placed at the head end of the longitudinal bar on the opposite side of the frame (Fig. 191).

Traction is applied by means of the Sinclair foot-board (Fig. 192). This is a board about 1 cm. thick, longer than the foot, and 9 cm. wide. In the middle is a longitudinal slit in which slides a bolt with a wing nut. This bolt passes through a hole in the middle of an iron strap long enough to rest on the side bars of the splint. The edges of the board are notched and padding is tacked on to the foot side. It is then fastened to the foot by narrow strips of gauze, tape, or flannel glued to the foot and ankle (preferably six or eight on each side), and passed in the notches of the

board to be tied together in pairs on the bottom. The traction cord is attached to the bight of a cord, which is, in turn, attached to holes in the ends of the iron strap. The position of the foot may be regulated at will according as the iron strap is bolted to the board.. If dorsal flexion is wished, the strap is fastened to the lower end of the slit, and vice versa. Rotation is controlled by the angle of the strap to the board, and inversion or eversion by changing the point on the bight at which the traction cord is tied. The Sinclair skate is another apparatus consisting of a plaster sole lined with saddler's felt, which is accurately modeled to the sole of the foot and glued to same. A piece of strap iron bent to a shape resembling a right-angled letter omega is embedded by its feet into the bottom of the plaster sole. The free portion of the omega iron has a slot in it corresponding to and serving the same purpose as the slot in the wooden skate. The plaster skate is used when wounds of the foot prevent the use of the wooden one. Traction by weights and pulleys is the most satisfactory; 15 pounds at first are usually sufficient and soon may be reduced.

Skeletal traction by means of a Codavilla pin through the os calcis or the Finochietto stirrup (Fig. 187) may be used, but is rarely indicated because sufficient traction ordinarily can be maintained by the Sinclair board or skate.

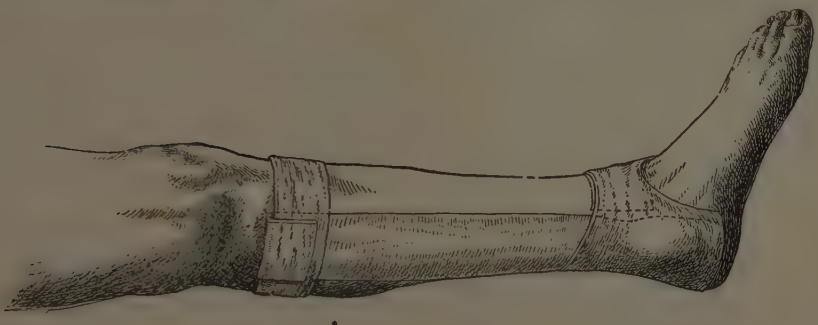
In splinting a fracture of the leg care must be taken that the foot is held in proper position or, in other words, that the fragments are not rotated. The anterior superior spine of the ilium, the patella, and the inner border of the big toe should be in line. Pain is often due to improper rotation, and immediately disappears when the foot is placed in a correct position. Posterior bowing, due to sagging, must be guarded against by supervision of the suspension slings, especially after dressings, to see that they are kept tight. Proper use of the Sinclair skate will prevent foot-drop.

Massage may be gently instituted from the first. The use of the supplementary hinged piece permits early mobilization of the knee. As union begins in the fracture the knee, ankle, and leg can be exercised actively in the splint.

When union is firm the leg may be removed from the splint and within a few days limited weight bearing begun.

In fractures with punctate wounds, particularly those without much comminution or displacement, plaster of Paris may be used as in simple fractures. When used, it should be applied in the manner of the Delbet splint (Fig. 193), that is, by lateral molded splints. Shell casts should never be used. The Delbet splint is remarkably efficient when properly applied, and is an ambulatory splint. It is excellent for cases of delayed union, which is not uncommon in these fractures, particularly of both bones. It consists of lateral molded plaster splints extending from the knee to the junction of the skin of the sole with that of the upper part of the foot, and two encircling bands of plaster, one just below the knee and the other just above the malleoli. These are applied to the vaselined or powdered skin. Shortening is prevented by the splint bearing

on tuberosities of the tibia and the malleoli. Unless skilfully and snugly applied the splint is unsatisfactory. This splint may be used in selected



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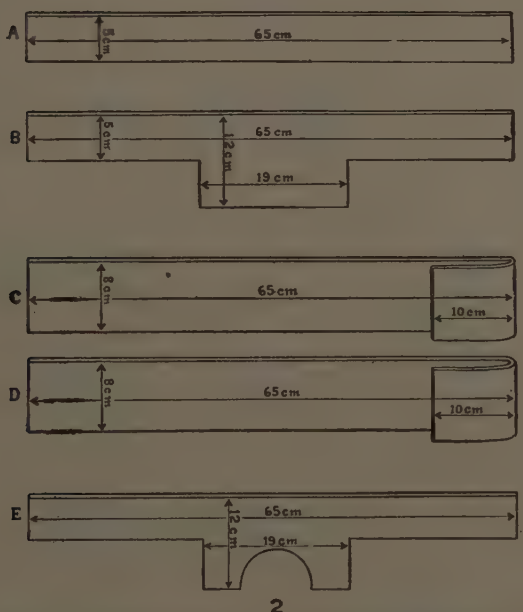

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FIG. 193.—DELBET'S AMBULATORY SPLINT FOR FRACTURE OF THE TIBIA AND FIBULA. (From R. Leriche.)

A. Upper band. B, Lower malleolar band. C and D, Lateral bands with folds 10 cm. long at inferior extremity. E, Lower band for the malleoli with notch cut in heel piece for heel. The bands are cut out of coarse weave crinoline to the dimensions shown, fourteen to sixteen thicknesses being used for the lateral bands and ten to twelve for the encircling bands. These are then thoroughly permeated with plaster of Paris by kneading them in a thin cream and immediately applied with a many tailed bandage, the latter being laid under the leg and the tails rapidly folded over the plaster bands, thus ensuring accurate coaptation of the latter before the plaster stiffens. Care should be taken to allow room for the play of the tibialis anticus tendon. In case of long heels the heel piece may be notched as in E.

cases of recent fracture, it being applied during reduction of the fracture by powerful traction.

Fractures of the Tibia Alone.—When the tibia alone is broken it is

splinted by the fibula, but not sufficiently to prevent angulation. The leg is best suspended with moderate traction as for fracture of both bones, and the same precautions should be observed.

Fractures of the Fibula Alone.—Compound fractures of the fibula alone may well be suspended for a time if the wound is of importance. If the wound is closed or insignificant, rest in bed or a light plaster splint, if the patient is up, is sufficient.

FRACTURES OF THE TARSUS AND METATARSUS

The treatment of gunshot fractures of the tarsus and metatarsus is of great importance both on account of the immediate danger to life from very rapid extension of infection along the tendon sheath to the leg, but chiefly on account of the loss of function which may result from improper methods. As the treatment of fractures of the tarsus is intimately connected with that of the ankle-joint, it will be considered elsewhere, and only the treatment of fractures of the metatarsus and phalanges will be considered here.

In the treatment of these injuries many of the considerations mentioned in fractures of the metacarpus apply, such as the employment of complete excision of the metatarsals and corresponding digits in order to avoid infection. In general, excisions in the longitudinal direction should be preferred, and excisions in the transverse direction should not be employed unless distinctly more than half the width of the foot is preserved. In injuries demanding more than this, amputation should be done. Although flaps made by turning down the sole of the foot have been made for the purpose of excision, the splitting incision through both dorsum and sole along the line of the metatarsals and tendons is much to be preferred.

It should be borne in mind that incomplete operations, particularly upon fractures by high explosives, are exceedingly dangerous, since in most of these contaminating material, such as leather or stocking, has been carried into the wounds, and unless removed there is danger of either fulminating infection or long tedious suppuration due to the death of bone. For these reasons it is generally inadvisable to leave any portions of the bones which have been directly contaminated. In the after-treatment the parts have to be immobilized for a long time in order to prevent deformity caused by cicatricial and muscular contraction. Weight should not be borne upon the foot until sensitiveness has disappeared, and when walking some form of apparatus or orthopedic shoe should be worn until all danger from contracture is passed.

APPENDIX

Major Sinclair's Formula and Instructions for Applying Traction Glued to Skin*

Test for Glue.—Place 4 ounces of glue in 4 pounds of cold water and leave in a cool place for twelve hours.

If dissolved	bad.
If coherent and gelatinous, weighing 8 ounces	good.
If coherent and gelatinous, weighing 16 ounces	very good.
If coherent and gelatinous, weighing 20 ounces	excellent.

The following is the formula:

Very good glue	50 parts
Water	50 "
Glycerin or glucose or calcium chlorid	4 or 6 parts
Menthol	1 part

Soak for twelve hours and then melt on a water-bath. Neutralize to litmus with sodium hydrate, as commercial glue at times contains free hydrochloric acid. Add 4 parts in summer and 6 parts in winter, of glycerin, and 1 part of menthol. Frequent heating evaporates the water, which should be added from time to time. When reheated many times, adhesive power is lost.

Technic.—(1) The skin is not shaved.

(2) Wash the skin with soap and hot water, which contains about 4 grams of washing soda to the pint, to convert the oil of the skin into soap, as glue will not adhere to a greasy surface.

(3) Dry the skin.

(4) Apply the warm glue evenly, brushing all the hairs of the limb in an upward direction.

(5) Keep a tension on the gauze all the time. Bring it quickly but carefully into contact with the limb (inner and outer surface), and apply neatly a loose-woven bandage, starting a handbreadth above the malleoli, up to the knee-joint.

(6) When dry, apply traction.

Note.—The adhesive can be made waterproof with a 2 per cent. solution of potassium bichromate applied in the dark and then exposed to the light, or by means of formalin (0.5 to 1 per cent.).

(7) The extension must always be very carefully applied, whether with Maw's elastic cotton net or with gauze.

(8) The extension must be changed at once if the patient complains of a tickling or burning sensation under it, but it generally requires changing about the tenth, twentieth, and fortieth days.

FORMULA FOR HEUSSNER'S GLUE

Resin	50 parts
Alcohol (90 per cent.)	50 "
Venice turpentine	1 part
Benzine	10 parts

* Personal communication from M. Sinclair, Major, R. A. M. C.

List of Splints, Splint Accessories, and Dressings for an Evacuation Hospital, 1000 Beds*

Splints:

Open bite intermaxillary splint	20
Snowshoe litters	10
Hinged modification of Thomas' arm splint	100
Thomas' traction leg splint	125
Hinged half-ring modification of Thomas' leg splint	100
Cabot posterior wire splint	200
Wire ladder splint	400
Long interrupted Liston splint	15
Splint wood, 3 feet	200
Splint wood, 4 feet	200
Galvanized net cone gauze	20
Splint rests, wire	300
Stretcher bars	50
Foot supports, wire	300
Wrist and hand splints	150

Splint Accessories:

Safety-pins, 1½ inch, gross	10
Safety-pins, 2¼ inch, gross	6
Straps and buckles, 1½ inch x 5 feet	300
Straps and buckles, 1½ inch x 6 feet	300
Slings	1000
Canvas hammocks	10
Plaster of Paris, cans	5
Jackinette, meters	10
ZO adhesive plaster	20
Sheet wadding, 5 x 5 inches, yard rolls	500
Stockinette, sizes 1, 2 and 3, of each	1
Crinoline, bolts	10
Felt, yards	500
Supporting slings, 8 x 21 inches	500
Supporting slings, 5½ x 16 inches	800
Supporting slings, 25 x 7 inches	500
Rubber cloth supporting slings, 8 x 24 inches	400
Rubber cloth supporting slings, 5½ x 16 inches	400
Glue, resin, and turpentine, liters	2
Glue, Sinclair's, cakes	2

Dressings:

Gauze rolls		1,000
Sponges or wipes, 2 x 2¼ inches	Packages	1,000
Sponges or wipes, 4 x 4½ inches	Packages	1,000
Absorbent pads		5,000
Paperback bed pads, Size 1, 10 x 18 inches		3,000
Paperback bed pads, Size 2, 18 x 23 inches		3,000
Bandages, 4 inch x 5 yards, muslin		500
Bandages, 5 inch x 5 yards, muslin		500
Bandages, 6 inch x 5 yards, muslin		500
Gauze bandage, 1 size		3,000
Gauze, plain, yards		10,000
Scultetus bandages		100
Jacket, pneumonia		10
Absorbent cotton rolls	Pounds	300

* Manual of Splints and Appliances, Medical Department, United States Army, Second Edition, 1918.

SPLINTS AND SPLINTING MATERIAL TO BE CARRIED BY EACH TACTICAL DIVISION*

	Splint distribution for regiment of infantry.			Total for each regiment of infantry.	Splint distribution for each regiment of artillery.		Total for each regiment of artillery.	For each ambulance company.	For each motor ambulance.	For each field hospital.	For each battalion of engineer and each non-combatant unit.	Total for a division.
	For each advanced infantry aid post.	For each infantry battalion aid post.	For each infantry regiment aid station.		For each battery of artillery.	For each artillery battalion aid post.						
Straps and buckles	2	6	6	36	2	3	†12–15‡	25	2	25	4	400
Snow shoe trench litter	.	.	.	.	.	.	.....	2	.	2	..	16
Thomas half-ring leg splint (Blake-Keller)	1	6	6	36	1	3	12–15	25	1	25	4	400
Thomas hinged arm splint (Murray)	1	6	6	36	1	3	12–15	25	1	25	2	400
Cabot posterior wire splint	1	6	6	56	1	3	12–15	50	1	30	4	450
Wire ladder splint	2	12	12	56	2	6	24–30	100	.	50	12	1000
Wood splints, assorted	1	6	6	36	1	3	12–15	50	.	25	2	450
Long Liston splint	0	0	0	0	0	0	0	4	.	4	0	20
Litter bars	0	10	6	36	1	6	15–18	50	1	25	2	400
Triangular bandages	6	24	24	200	6	12	60–72	200	.	200	24	3000
Cotton (wadding) Rolls (batting)	0	4	4	16	0	0	4–6	25	.	25	10	350
Muslin bandages, 4 and 6 inch, assorted	6	24	24	120	6	12	60–72	200	.	200	12	1500
G. O. adhesive 2½ inch rolls	1	6	6	36	1	1	12–15	30	.	30	6	400
Wire foot supports	0	10	6	36	0	3	15–18	50	.	50	2	500
Wire gauze rolls	0	0	0	0	0	0	0	0	.	25	0	100
Sinclair's glue	0	0	0	0	0	0	0	0	.	½ kil.	0	2 kilos
Adjustable traction straps	1	6	6	36	1	3	12–15	25	1	25	4	400
Hand and wrist splints	1	3	3	18	1	2	6–8	15	1	15	2	250

* Manual of Splints and Appliances, Medical Department, United States Army, Second Edition, 1918.

† The first column is for regiments of 2 battalions each.

‡ The second column is for regiments of 3 battalions each.

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CHAPTER XVIII

THE PATHOLOGY OF GUNSHOT WOUNDS AND OTHER SEVERE INJURIES OF THE NERVOUS SYSTEM

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SECTION I

The Brain

While considering the characteristics of the alterations of the brain produced by gunshot wounds and other injuries of the head, many of which occur in civil practice, their extent, as well as their location, must be kept in mind.

Injuries of the head can be divided into two general groups: (1) Those affecting the brain directly, as in laceration by a penetrating gunshot wound, and (2) those in which damage occurs indirectly, as the result of the impact of a blow upon the skull, as in falling from a height, or of a bullet or other missile that has not penetrated the brain substance; in this group are included also the effects of contusion and concussion.

Physiologists agree that compression cannot occur in the sense that the brain can be squeezed or pressed together into smaller limits, but pressure upon the brain, usually from hemorrhage and depressed fracture, is very common. Abscess and meningitis are frequent complications.

More than one of these factors are generally present, for in most severe direct injuries to the brain, whatever the cause, a certain amount of damage, dependent upon contusion and concussion, is inflicted on the brain. If the injury is localized, the general ill effects are not entirely irreparable; hence it should be borne in mind that loss of function does not always indicate the extent of structural damage that has taken place, particularly in the early stages.

The clinical course of cerebral injuries should, therefore, be regarded as representing two periods—the primary and secondary stage. The former corresponds to the stage of shock, and is characterized by loss of consciousness, muscular flaccidity, and disturbance of the cardiac and vasomotor action. These phenomena denote suspension of function, which may terminate in spontaneous recovery or in death. The nature of the pathologic changes that take place in the brain and that are necessary for the production of these phenomena is not clearly understood, but during the first stage swelling of the whole brain, the result of edema, is known to occur. Edema may be intense and gen-

eralized, or in milder cases may be confined to the site of injury. It may continue for several days, and then, if no complications arise, subside spontaneously. Moreover, when an injury occurs, as, for example, in the motor area of the cortex, the effect of destruction of the neurons is manifested not only in the spinal mechanism but also in all other parts of the central nervous system to which nerve-fibers pass from the site of the lesion. The effect of abrupt cessation of the normal activity of these nerve-fibers is, therefore, evidenced in these other portions of the nervous system in the form of shock. Von Monakow[50] gave to this condition the name "diaschisis." Later the affected parts become readjusted and functional activity becomes more nearly normal. It is highly probably that, with the subsidence of cerebral edema, when this is present, this restoration of function is hastened. For this reason Leriche[41] and others have emphasized the value of lumbar puncture in treatment, in the belief that, by diminishing cerebrospinal pressure, the swelling and edema, together with the associated phenomena, subside more rapidly. But it is known that meningitis not infrequently occurs shortly after removal of spinal fluid by lumbar puncture, and Wegeforth and Latham[78] have demonstrated that withdrawal of cerebrospinal fluid during the course of artificial septicemia in animals is followed by a localization of the infection within the meninges. These observations indicate that under certain conditions the removal of spinal fluid should be seriously considered as a causative factor in the production of meningitis.

The secondary stage sets in after all evidence of shock has disappeared and restoration of function of the affected portions of the brain is proceeding gradually. Experience has shown that in most cases considerable recovery of function takes place.

Direct lacerations and destruction of the brain from penetrating wounds are easily recognized. In some instances large amounts of brain substance may be destroyed and even extruded from an open wound and the patient yet survive.

HEMORRHAGE

Intracranial hemorrhage is the most common cause of serious symptoms following injury of the head. Profuse intracerebral hemorrhage is rarely associated with gunshot wounds of the brain, yet occasionally a large blood-vessel is lacerated by the penetrating missile, and extensive hemorrhage ensues. Whatever the cause, hemorrhage within the brain is extremely serious, and unless very small is nearly always fatal. Normal blood-vessels do not rupture spontaneously. Vascular disease is the only known cause of spontaneous hemorrhage within the brain substance. Sargent and Holmes[59] emphasized the rarity of cases of penetrating gunshot wound in which hemorrhage is sufficiently large to threaten life, or so well localized as to demand surgical interference.

Hemorrhage in the subdural space after trauma generally collects in the sulci of the brain, becoming more abundant in the basal region.

It may even be entirely limited to this region, but is often extensive, most of the convexity of the brain being covered by a thin layer, and even extending into the fourth ventricle and the spinal canal. Occasionally the sheaths of the optic nerves are distended with blood. Blood in the spinal fluid removed by lumbar puncture is sometimes of considerable value in differentiating between intracerebral and meningeal hemorrhage. Small hemorrhages coming from the cortical veins or meningeal vessels, associated with local edema of the brain tissues, are frequently found with depressed fracture. Meningeal hemorrhage may, however, occur independently; Spiller[65] observed the case of a man who had received a blow upon the head and who subsequently developed extensive bilateral subdural hemorrhage of the frontal region without paralysis or fracture. Guillain[27] asserts that meningeal hemorrhage from simple contusion of the skull is much more common than is generally recognized.

VENOUS HEMORRHAGE

Primary injuries of the cerebral veins are not common in civil practice. In military practice, however, disturbances of the cerebral venous circulation from depressed fracture are not rare. The statistics of Velter[75] show that injuries of the transverse and lateral sinuses usually cause fatal hemorrhage. Holmes and Sargent[36] found that injury of the superior longitudinal sinus was quite common and relatively less serious after gunshot wounds, most often of the "gutter" or tangential type, at the middle line of the skull, generally with fracture of the inner table.

The mode of entrance of the veins into the longitudinal sinus has an important bearing on the symptoms produced by lesions in the neighborhood. The superior cerebral veins do not open directly into the superior longitudinal sinus, but into the walled lacunæ that project from it over the lateral and mesial surfaces of the hemispheres. The parietal lacunæ extend farthest over the convexity of the hemisphere, and, owing to the thinness of their walls, are easily occluded, consequently any depressed fracture or direct injury in their neighborhood may block the venous circulation of the upper part of the central convolutions.

Thrombosis of the longitudinal sinus is usually found at operation, its character depending upon the duration of the condition. In many instances the sinus is not completely occluded. The superficial cortical veins, which enter the sinus at the site of the wound, appear to be greatly distended and firm to the touch. The upper portions of the hemispheres that are drained by these veins are swollen, and convolutions are flattened from pressure against the skull, but are firm to the touch. The cortex and subcortex are edematous and the seat of numerous minute hemorrhages in the region of the wound. Actual softening may take place. Subdural hemorrhage is wide-spread, forming a thin film of blood over the convexity of the brain; in some cases it extends to the base, tinging the spinal fluid. The severe headache which is often pres-

ent is probably caused by an increase in the intracranial pressure. The most important change seen under the microscope is edema, which is more marked in the white than in the gray substance. Many of the superficial veins are occluded, the nerve-cells are swollen, and the chromatolysis is marked.

Paralysis varies in distribution with the site of the injury, all four limbs being frequently affected, but weakness of the face and tongue is very uncommon. The relative severity of paralysis in different segments of the limbs is peculiar, differing from the cerebral palsies seen in civil practice. In the upper limbs the most proximal segments are those most severely affected, weakness diminishing distalward. In paralysis due to vascular disease the distal portions of the limbs are generally affected more than the proximal segments.

In the lower limbs the distribution of the paralysis and its relative severity in the different segments are dependent upon the arrangement of the cortical motor areas and the central veins.

The damage to the nerve-cells and nerve-fibers is not always irreparable or complete, hence recovery of function frequently occurs.

CEREBRAL CONTUSION

The terms "contusion" and "concussion" are frequently confounded, no exact limitations having been defined.

As employed here, contusion is applied to local bruising or crushing of the brain and its coverings by the violence of the impact of a missile upon the skull, the damage done being chiefly at the point of injury or close to it. By concussion is meant the violent shaking and vibration of the whole brain by jarring, the result of trauma. Obviously, contusion and concussion may occur at the same time. It might appear, at first thought, as though the one condition could not be present without the other, and yet at autopsy certain changes have been found in the brain that seemed to justify separating the effects produced by contusion from those the result of concussion. Typical cases of contusion *per se* are generally caused by bullet wounds with fracture of the inner table of the skull, but the impact of a missile may cause contusion of the brain without fracture.

The effect upon the brain is quite well localized, and consists chiefly of edema, thrombosis of the cortical vessels, punctate hemorrhages, swelling of the nerve-sheaths, and chromatolysis of the nerve-cells of the cerebral cortex at the site of the injury, and in the area immediately surrounding it. In the milder cases the damage to the nerve elements is only slight, so that function may be almost completely restored. In the more severe types, however, the pathologic changes go on to complete disintegration of tissue and actual softening. As the lesions are generally limited to the cortex of the brain, and since the subcortical tissue is not, as a rule, markedly affected, the loss of function after all effects of shock have subsided may differ from the types of paralysis occurring as the result of lesions situated more deeply within the brain substance.

CEREBRAL CONCUSSION

In this condition the most constant findings are minute punctate hemorrhages, chiefly within the white substance. In severe cases these hemorrhages have been found scattered irregularly throughout the brain, including the cerebellum, cerebellar peduncles, pons, and medulla oblongata. Shock may be profound, and even result in death. Frequently, on postmortem examination, no structural change can be found, but microscopic examination may reveal varying degrees of chromatolysis of the nerve-cells. These are, however, generally ill defined, and while probably not always irreparable, may account for the peculiar mental state that often follows severe concussion and fracture of the base of the skull.

Many cases of cerebral concussion due to the bursting of high explosives in warfare have been recorded. These have been attributed by Léri[40] and others to lesions of the brain, particularly meningeal hemorrhages, encephalitis, softening, etc. That such lesions do occur there can be no doubt. Mott[51] described certain changes, consisting chiefly of minute hemorrhages, found by him in the brains of 2 cases of uncomplicated aërial concussion. Although the "concussion syndrome" and its pathology were clearly recognized by the A. E. F. in France, many of the suspected cases were subsequently shown to be suffering from a psychoneurosis (Schwab[60]).

INTRACRANIAL INFECTION

Primary meningitis and encephalitis are the most frequent and most dangerous complications in the early stage of gunshot wounds of the head, particularly in those caused by high explosive shells, since foreign substances are so often carried deep into the wound. In the later stages meningitis is relatively rare. Even in the absence of an open wound micro-organisms may gain entrance to the cranial cavity when the dura has been torn, passing along the line of fracture at the base of the skull, when it involves the middle ear or the frontal sinus. In gunshot wounds and other penetrating injuries suppuration usually begins in the scalp, close to the site of the injury, extending gradually to the meninges. The process may be localized at first, but, owing to the development of adhesions between the dura, the pia-arachnoid, and the superficial soft parts, the infected area may become walled off, thus constituting a veritable extracerebral abscess, with focal symptoms from irritation and pressure. These are the cases in which surgical intervention yields the best results.

Sargent and Holmes,[59] as well as Makins,[43] utter a caution against breaking up adhesions at operation. They point out that adhesions between the edges of the dural wound and the contiguous pia-arachnoid form the chief safeguard against generalized infection. By their means the arachnoid space is shut off, the process being assisted by the pressure of the swollen brain against the dural opening. Occasionally after gunshot injuries, owing to the increased intracranial pressure, generally believed to be associated with edema, the brain protrudes through the

opening in the skull. Reichardt[56] observed a peculiar type of acute swelling of the brain which may be associated with "hernia cerebri." Spiller[67] described the permanent enlargement of the brain associated with brain tumor, which, he believes, is the result of proliferation of the neuroglia tissue, adding other manifestations to the symptoms of the tumor, more particularly, in some cases, impairment of mentality. This is a condition produced by irritation and may result in chronic encephalic irritation in any form.

Sargent[58] classes as "fungus cerebri" the strangulated, disintegrated, and partly necrotic mass of brain substance forming cauliflower-like excrescences that are connected with the intracranial contents by a relatively narrow pedicle. He regards as "hernia cerebri" the relatively intact brain matter covered by the unruptured pia-mater protruding through an opening sufficiently large to obviate strangulation.

Experience has shown that infection of the brain rarely occurs if the dura mater has not been damaged, and, conversely, if the dura has been lacerated, as in gunshot wounds, the danger of infection is always great.

Lapointe,[38] in discussing head injuries in warfare, refers to the comparative harmlessness of extradural injuries and the fearful mortality from infection when the dura has been lacerated. In civil practice, however, purulent meningitis, if the process is not too diffuse, is not always fatal. Shields, Spiller, and Martin[61] describe the case of a child with localized purulent meningitis secondary to pansinusitis, with complete recovery after operation. Since then similar cases have been recorded, one by Leopold.[39]

Not uncommonly infection remains latent for a time, but tends to follow the tract of the missile, producing extensive encephalitis. Microorganisms burrow deeper and deeper; at times a sinus is formed that ruptures into the lateral ventricles, carrying the infection through the entire cerebrospinal system, and setting up a generalized purulent cerebrospinal meningitis that is rapidly fatal. Essick[21] found that in 50 per cent. of his cases of traumatic abscess produced experimentally infection reached the ventricular system within a few days. Furthermore, a focus of pus in the brain may remain walled off for a considerable length of time, even after the external wound itself is almost healed, later giving rise to abscess formation. Holmes[33] states that most of the late cases of abscess occurred between the third and sixth month after injury. Marburg[44] refers to cases of brain abscess following gunshot wounds developing five months after operation. Von Eiselsberg[20] and Villaret and Faure-Beaulieu[76] record similar observations. Although these observations clearly show the danger, the development of abscess at so late a day is relatively uncommon.

Cerebral abscess the result of infection from the middle ear is almost invariably situated in the temporosphenoidal lobe of the affected side or the cerebellum. This is due to the close relationship of the lobe to the roof and posterior wall of the tympanum. According to Tylor,[74] the path of infection may be through the tegmen tympani, the mastoid

antrum, cells, or posterior tympanic wall; or the infective material may be carried from the ear by the blood-stream and finally enter the cerebral circulation, becoming arrested in one of the diminutive arterioles, and resulting in pyemic abscess.

FOCAL SIGNS AND SYMPTOMS

Frontal Lobe.—In spite of many recorded observations the exact physiologic function of the frontal lobes is unknown, but Marie and Benhague[45] have demonstrated an important clinical syndrome, resulting from deep lesions of the frontal lobe, consisting of a disturbance of the sense of direction, or, as they call it, a "disorientation" in space, but without disturbance as to the sense of time. It may vary from a simple disturbance of the finer sense of direction to total loss of that sense, the intensity apparently corresponding to the depth of the lesion. Lesions of the oculomotor and optic nerves are not infrequently caused by gunshot wounds of the frontal area.

MOTOR AREA

The "excitomotor" area of the cerebral cortex is that portion which gives origin to the pyramidal tract; it is situated almost entirely within the precentral convolution. Head[30] states "it is not coterminous with the so-called sensory cortex."

The motor centers are so grouped in the cerebral cortex that small localized lesions may cause loss of function in one limb or in part of a limb. Paralysis of one segment of a limb is not often encountered in civil practice, but has frequently followed gunshot wounds. Spiller[70] cautions against confusing segmental cerebral monoplegia with peripheral nerve lesions and hysteria. Head[30] also points out that cortical paralysis *per se* may vary from day to day, being indefinite and incomplete in character, phenomena that should not be regarded as evidence of their functional origin, for, in contrast to the profound paralysis of subcortical lesions, these manifestations are peculiar to pure cortical paralysis.

SENSORY CORTEX

The parietal lobe is regarded as purely sensory in function. According to Head,[30] the sensory cortex consists of the precentral and postcentral convolutions, the anterior part of the superior parietal lobes, and the angular gyri.

Lesions of the sensory cortex are marked by phenomena known collectively as "astereognosis" and "atopognosis," consisting of the loss of power to recognize spatial relationships and of correctly locating sensations. Hypotonia of the paralyzed limb or segment of a limb is also frequently present.

The peculiar condition known as "apraxia" has been attributed to a disturbance of function of the supramarginal gyrus. Liepmann, who has made a study of this condition, has defined motor apraxia as the incapacity for subjective purposive movements of the limbs, with con-

servation of the power of movement or an inability to combine a simple movement into complete purposive acts. An apraxic patient is, for example, incapable of making proper use of objects, as a key or a knife, although he is entirely mindful of what is required. Smith and Holmes[63] described a case of this kind following a penetrating gunshot injury in the region of the supramarginal gyrus.

Lesions of the angular gyrus may cause word blindness. Hinshelwood[31] has observed such cases, but Marie disputes the existence of *uncomplicated* or *pure* word-blindness.

Lesions of the lateral surfaces of the hemispheres, particularly of the parietal regions, may give rise to disturbances of the higher visual percipient functions, with intact visual sensibility and other phenomena (Holmes[34]).

TEMPORAL LOBES

The function of the temporal lobe is generally believed to be essentially that of hearing, and bilateral lesions of the superior temporal convolutions are said to be capable of causing deafness or so-called cortical deafness. A lesion confined to the posterior half of the first left temporal gyrus, in a right-handed individual, may induce word-deafness, a condition marked by inability of the patient to understand spoken words, although he may be able to hear sounds distinctly. Like word-blindness, according to the conception of Marie and his pupils, Chaterlin and DeMartel,[13] the clinical picture of pure word-deafness and its anatomic localization are entirely theoretic. Further discussion of this topic would involve the entire subject of sensory aphasia, which is clearly out of place here. Nevertheless, word-deafness, so called, may be of value as a localizing sign.

OCCIPITAL LOBES

The visual area is situated in the occipital lobes, and is limited especially to the cortex of the calcarine fissure. In this region the cells, when seen under the microscope, present a different appearance from those of other portions of the brain cortex. The superior lip of the calcarine fissure of one side corresponds to the upper quadrant of the retina in each eye, whereas the lower lip corresponds to the lower quadrant of each retina.

Extensive destruction of both occipital lobes or of only part of the visual area will result in cortical blindness, as shown by the report of Holmes and Lister,[35] but Bramwell, Bolton, and Robinson[5] have observed that macular vision may be retained. Other disturbances of the visual field, such as homonymous lateral hemianopsia, quadrantic hemianopsia, scotoma, etc., are frequently observed.

CEREBELLUM

Wounds of the cerebellum are rare. Although our knowledge of the physiology of the cerebellum is limited, lesions of this structure are known to produce certain phenomena, collectively termed the cere-

bellar syndrome, consisting in ataxia, the component parts of which are recognized as—(*a*) "dysmetria," which is again divided into "hypermetria" and "hypometria," terms used to designate degrees of disturbance in the performance of voluntary movements; (*b*) "adiadokokinesia," an inability to execute rapidly successive voluntary movements; (*c*) "asynergia," or a loss of the association of movements because of the lack of synchronization. André Thomas[3] described abnormalities in the function of the antagonistic muscles of a limb, and Holmes[33] observed hypotonia following injury of the cerebellum.

Because of the proximity of the visual centers disturbances of vision are not uncommonly associated with injuries of the cerebellum.

SECTION II

Pathology of Gunshot Wounds and of Other Injuries of the Spinal Cord

Postmortem examinations following gunshot wounds and other injuries of the spinal cord have shown clearly the distinctive character of lesions likely to be present in the majority of cases, and have demonstrated the value of certain clinical signs as indicating the presence of these lesions.

Although traumata may differ widely in nature, the effects upon the spinal cord are of the same general character. As a rule, severe traumata produce extensive alterations of the cord, although serious intramedullary lesions may result from traumata that at first appear to be insignificant in nature.

The method by which the direct lesion is produced is clear. Complete division of the spinal cord by a bullet is not rare.

Direct lesions are also produced by a bullet moving rapidly across the spinal canal, which contains fluid under pressure, as well as the cord itself—a fact often overlooked. The sudden and severe increase of pressure-effect is transmitted to the entire nerve supply within the cerebrospinal space. Even when the missile does not touch the cord or lacerate the membranes, the damage to the spinal cord will be greatest at that point where the bullet has crossed, although the affected area may extend for a considerable distance above and below this point. The sudden increase of pressure is believed so to affect the brain as to produce immediate loss of consciousness. This symptom occurs so frequently in these cases that Collier has suggested that initial loss of consciousness may be regarded as an indication that the bullet has traversed the spinal canal. This, he believes, is particularly true of injuries of the cervical region. Claude[14] has described a group of symptoms which he terms the syndrome of hypertension of the cerebrospinal fluid following concussion, the result of trauma of the posterior cervical region. In this condition the symptoms, consisting of headache, vomiting, vertigo, hyperemia of the retinal veins, paralysis of the cranial nerves, and evidences of irritation of the cervical sympathetic nerves, were completely relieved by lumbar puncture.

Severe lesions may be induced indirectly by impact resulting from the passage of a high velocity bullet in the immediate vicinity of the spinal canal, by impact of a projectile upon the bones forming the spinal canal, even though the walls of the canal remain intact, or by concussion.

This is illustrated by the following case:

M. C. C., a soldier, was struck by a machine-gun bullet. The wound of entrance was in the middle of the left scapula; there was no wound of exit. The patient immediately became paralyzed. *x*-Ray examination showed the bullet to be lodged between the bodies of the third and fourth thoracic vertebræ. There was complete motor and sensory paralysis, with loss of sphincter control and absence of the tendon reflexes of the parts below the corresponding segments of the cord. The patient died three weeks later. At autopsy the meninges were found to be intact; the contour of the spinal cord was not altered, but at the site of injury the cord was seen to be swollen and soft. The cord tissue was completely pulpified, and of custard-like consistency over an area nearly the extent of two segments. No hemorrhage was apparent to the naked eye.

Softening of the spinal cord, therefore, may occur solely as the result of impact of a projectile without accompanying laceration of the meninges.

Souques and Demole[64] have observed a case similar to the one just described. The experimental work of Allen[2] has proved that the extent of such cord lesions is dependent largely upon the force of the impact.

Pressure upon the spinal cord is always secondary or indirect, since it is invariably due to a foreign body, such as a bullet, a fracture dislocation, or a spicule of bone; occasionally an epidural or an intradural hemorrhage may cause pressure and irritation of the nerve-roots, particularly of the epiconus. The hemorrhage tends to collect around the lumbar enlargement and the cauda equina. Von Eiselsberg[20] called attention to the fact that intradural hemorrhage may become completely absorbed, but that when it is not entirely absorbed, the blood may undergo organization and give rise to pachymeningitis or the so-called meningitis serosa circumscripta. This subject has also been investigated by Mauss and Kruger.[48]

Uncomplicated intradural hemorrhage is, however, rarely the cause of paralysis from pressure upon the cord, although dural hemorrhage may in some instances be more or less localized or circumscribed. Experience has shown that intraspinal hemorrhages are very rarely extensive enough or sufficiently well localized to constitute an indication for operation. Early recognition of such hemorrhages, in the stage in which removal of the blood by lumbar puncture can be performed, is apparently impossible.

The observations of Holmes,[32] Collier,[15] and Frangenheim[23] show that lesions within the cord substance caused by impact and concussion after gunshot wounds are not necessarily associated with pressure. On the other hand, pressure upon the cord by malposition of bones or by the presence of a bullet is also common and in itself constitutes an indication for operation.

The seriousness of the pressure is dependent upon its degree, its duration, and the mode of onset. If it is suddenly inflicted, the condition is an extremely serious one, and may equal in gravity laceration and crushing with the dura intact. When, however, the pressure is moderate and begins gradually, the condition is much less serious. In mild cases pressure does not always result in irreparable damage, provided it can be removed early.

In some instances in which pressure has existed for some time without causing paralysis the latter may be ushered in suddenly. This has been observed in Pott's disease[6] without deformity of the vertebræ. Such cases are, however, unusual. The cause of the suddenness of the onset of the paralysis is not entirely clear, but may be due to thrombosis of the spinal vessels. Spinal thrombosis is not a rare complication of syphillis, and is probably the etiologic factor in most of the apoplectiform spinal pareses seen in non-traumatic myelitis.

Normally, the spinal cord is softer and more vascular than many of the other tissues of the body. The central gray matter is the most vascular portion of the structure, and since the blood-vessels in this region are only loosely held together by the neurogliar tissue, which is much less firm and dense than the connective tissue in other parts of the body, hemorrhage generally takes place in this part of the cord.

Hematomyelia is a common result of gunshot injury or of any other severe trauma. Under the head of "hematomyelia" some authors include hemorrhages occurring within the gray matter, and which may be only microscopic in size, as well as hemorrhage that originates in the central gray substance and which may become so extensive as to invade and occupy the entire cross-section of one or more segments of the cord. This use of the term leads to confusion. More generally the term hematomyelia is used to designate a hemorrhage that is visible to the naked eye, and does not include the minute extravasation of blood-cells that are recognizable only on careful microscopic examination.

A fact not difficult to appreciate is that traumata, even when of slight degree, by violently agitating so delicately arranged a structure as the cord, which contains blood-vessels that are not firmly supported by dense connective tissue, may give rise to hemorrhage. Moreover, when hemorrhage does occur within the cord, more or less softening or myelomalacia must ensue. Formerly it was considered doubtful whether traumatic myelomalacia could exist unless accompanied or preceded by hemorrhage, yet Souques and Demole[64] made microscopic examinations in serial sections of a spinal cord in which there had been severe softening following the concussion of a gunshot wound, and were unable to find any evidence of hemorrhage. In cases of concussion Holmes has also observed focal softening entirely unrelated to the hemorrhage which is usually present. On the other hand, in the absence of trauma, hemorrhage within the spinal cord is of doubtful occurrence unless associated with vascular disease, since normal blood-vessels do not rupture spontaneously. This is also true of the brain. I have called attention

to this finding and referred to the rarity of spontaneous intracerebral hemorrhage in animals.[7]

In severe concussion or contusion from the impact of a bullet irregular areas are found, sometimes widely separated, consisting chiefly of focal softening or of patches of necrosis, vacuolation of the white matter, swelling and disintegration of the myelinated fibers, and irregularly scattered hemorrhages. The special characteristics of these lesions are their diffuse and irregular distribution and their tendency to diminish gradually from the point of maximal disturbance. According to Holmes, the essential change consists of primary disturbances in the vitality of certain portions of the tissue, associated with edema and frequently with small scattered hemorrhages. Subsequently degeneration of the ascending and descending tracts of the spinal cord may take place.

These pathologic changes are those usually produced by gunshot wounds, as well as by other severe traumata. In the early stages they generally constitute complete physiologic section of the cord. Occasionally, when the spinal cord is exposed at operation, serious intramedullary lesions may exist without manifesting any external evidence; if, however, the concussion has been severe, the affected segments of the cord may appear swollen and edematous. It was this which led Allen[1] to suggest the operation of incision and drainage of the cord substance. In cases of constriction from pressure or laceration the contour of the cord may be greatly altered.

The belief formerly existed that severe indirect injuries of the spinal cord occurred solely as the result of concussion by bursting of high explosive shells without the infliction of an external wound, without any apparent lesion of the bones, and even without bruising of the soft parts. This subject was discussed at a meeting of the Neurological Society of Paris by Vincent,[77] who classified the nervous manifestations occasioned by shell explosion into: (1) Emotional phenomena; (2) commotional (concussion) phenomena, and (3) mental phenomena.

In the second group of cases he observed certain pathologic modifications, such as meningeal hemorrhage and hemorrhagic and traumatic encephalitis. Léri[40] has also described similar alterations. Guillain[28] believes that many cases were formerly erroneously considered functional that were really organic in nature. On the other hand, Roussy and Boisseau[57] concede that such cases do occur, but that they are only very exceptionally produced by aërial concussion.

It is a striking fact that the vast majority of these cases can be cured by psychotherapy, and because of this most neurologists are of the opinion that the phenomena that develop after severe aërial concussion are purely psychic in nature, although they do not deny the occasional occurrence of actual damage to the central nervous system. The experiences of the A. E. F. in France clearly justify this latter opinion.

MENINGITIS

In cases of gunshot wounds in which the dura has been lacerated purulent meningitis is very prone to develop. Guillain and Barre[29] point out that purulent meningitis is more apt to develop when the dorsolumbar or the sacral region is the seat of the trauma. Once meningitis has set in, it progresses rapidly, extending upward and involving the brain and frequently causing death in from twenty-four to forty-eight hours. Meningitis may develop after gunshot wounds of parts widely remote from the cerebrospinal axis, even when there is no laceration of the dura. Orr and Rows[52] have shown that the central nervous system may become infected from a focus of pus in no way connected with the nervous system, the infecting organisms traveling directly to the spinal cord by way of the lymph-vessels of the peripheral nerve-trunks. The following case was observed in France:

A. J. C., a gunner, was wounded in the right flank, in the region of the right kidney, by a shell. As was usually the case, the wound became infected and discharged pus. The missile had entered deeply into the muscle of the loin, but had penetrated neither the abdominal cavity nor the spinal canal. Eight days after injury the patient developed symptoms of septicemia and meningitis and died on the tenth day. At autopsy the dura was found to be intact, but there were evidences of severe spinal meningitis which had ascended to the brain. Masses of polymorphonuclear cells infiltrated the pia, and diffuse purulent meningitis was easily recognized, even with the naked eye.

During the recent war cases of this kind following shell wounds were not so rare as was generally believed, and even in civil practice the possibility of infection of the central nervous system resulting from abscess or other infecting focus outside the cerebrospinal canal should not be overlooked. Spiller[66] described a case in which myelitis developed in conjunction with a perirectal abscess. He believed that the infecting organism had reached the spinal cord by way of the nerve-sheaths.

CAUDA EQUINA

Injuries of the cauda equina the result of gunshot wounds are not uncommon.

From a surgical viewpoint the nerve-roots comprising the cauda should be regarded as peripheral nerves, since when injured they are capable of undergoing complete regeneration, and recovery from paralysis is, therefore, very frequent.

Following an injury, more or less localized pachymeningitis may develop and adhesions between the roots are also frequently found, conditions that most commonly interfere with regeneration and restoration of function.

In addition to the usual motor and sensory phenomena that arise as the result of injury to the cauda equina, Fearnsides[22] observed paralysis of the large intestine and rectum and recurrent attacks of intestinal obstruction; the latter he attributed to destruction of the pelvic autonomic nerves.

In civil practice injuries of the cauda equina are not infrequent. Sudden overflexion or hyperextension of the spinal column may severely

stretch the roots of the cauda, and in this way give rise to marked paralysis of the lower limbs. The paralysis is generally limited to the peroneal group of muscles. The prognosis is favorable. Spiller[68] refers to cases of this type and also mentions the condition described by Fuchs, of Vienna, under the name of "myelodysplasia." He applied the latter term to certain anomalies of development often associated with spina bifida occulta, the important features of which are enuresis nocturna, persisting after puberty and due to weakness of the vesical sphincter, mild disturbances of sensation, especially of temperature, deformities of the sacral canal recognizable by the roentgenograms, anomalies of the tendon reflexes, and defects in the feet. Other anomalies, such as hypertrichosis of the sacral region, lipoma in the coccygeal region, and fistula-like depression of the sacrococcygeal region, should also be sought for.

In military practice a persistent enuresis nocturna is sometimes misinterpreted and has even been regarded as a phase of malingering. Individuals so afflicted may suffer no inconvenience except after strenuous exercise, as following prolonged marching. Weakness of the legs, particularly of the peroneal muscles, may be the first indication of the presence of this condition.

SECTION III

The Pathology of Gunshot Wounds and Other Injuries of the Peripheral Nerves

In order to appreciate the effects of various traumata upon peripheral nerves, the arrangement of the elementary structures of a normal nerve, the method of repair after injury, and the nature of the conditions that interfere with the normal reparative processes must be understood.

NORMAL ANATOMY

A normal peripheral nerve is made up of numerous axis-cylinders, each surrounded by its medullary substance and enveloped by a delicate membrane—the sheath of Schwann. The fibers are aggregated into bundles separated by connective tissue, or *endoneurium*, these in turn being surrounded by the *perineurium*, all enclosed in a tough connective-tissue sheath. The blood and lymphatic vessels, some of which communicate with the central nervous system, pass between the fibers and between the bundles of fibers. Orr and Rows[52] have shown that infection of the central nervous system may occur by the passing of organisms from the periphery by way of these vessels. (This is referred to also under Pathology of the Spinal Cord.) Each motor fiber is the prolongation of a nerve-cell situated within the gray substance of the anterior horn of the spinal cord. In the case of a cranial nerve, however, the cell nucleus is in the brain stem, which is the homolog of the anterior horn cell of the spinal cord. Each sensory fiber arises from the posterior spinal root ganglion of the cord or its homolog within the skull. These fibers extend to the periphery, terminating in the end-plates.

Recent investigations have shown that variations occur in the number and arrangement of the fibers of different nerve-trunks, as well as in the same nerve. Greenman[26] has found in rats variations of the area occupied by the axis-cylinder as compared with the area of its medullary sheath. Moreover, age, nutrition, general health, and bodily vigor are factors influencing these variations.

Stoffel[72] has endeavored to demonstrate that in every peripheral nerve-trunk certain localizations of the bundles of fasciculi occurred, these being arranged according to their special and definite function. He believed that his systematic localization was constant. Later Marie, Meige, and Gosset,[47] by a method of electric stimulation, arrived at similar general conclusions.

Putti[54] and Barile[4] believe that definite localizations can be established. More recently, however, Dustin,[19] recognizing that a knowledge of the disposition of the nerve-bundles in the trunks of peripheral nerves is important in nerve suture, examined various nerve-trunks and showed that wide variations of fasciculation existed, some being more richly fasciculated than others, the type not being characteristic of any particular nerve. Dustin also found that essential bilateral symmetry did not occur. Thus in a given trunk the type may vary and constant division and reanastomosis of the fascicular plexus take place. He concluded that the results obtained by electric stimulation may be misleading, and that functional systematization on an anatomic basis is not yet possible.

Investigations to determine these points present many difficulties, and further researches must be conducted before dogmatic statements can be made.

REGENERATION AND DEGENERATION

The views regarding the method by which regeneration takes place after injury to the peripheral nerves have been modified from time to time, but it is now generally conceded that regeneration occurs as the result of the outgrowth of axis-cylinders from the central end of the divided nerve.

If a peripheral nerve is divided, the distal segment undergoes complete degeneration, the myelin becomes swollen, the sheath of Schwann distends, and the neurilemma cells proliferate. The myelin substance is broken up into irregular masses that, if stained with osmic acid, appear black under the microscope. The axis-cylinders become fragmented, twisted, snarled, and shrunken, and finally disappear entirely. After the peripheral segment has undergone complete degeneration only the sheath of Schwann remains, which resembles a thin strand of connective tissue; a few scattered granules and droplets of myelin may also be seen. A similar process takes place in the distal portion of the central stump of the divided nerve, but it extends proximally only a few centimeters. The ends of the divided nerve then become swollen and present a club-shaped appearance. Almost immediately, or within a few days, axis-cylinders begin to grow from the proximal stump. At first these are non-medullated and arranged parallel to one another.

Perroncito[53] and others have demonstrated that, as the axis-cylinders extend, the young axons undergo division, and in many cases a single fiber divides and branches, giving rise to many offshoots. Ranson[55] observed that in laboratory animals the branching of medullated nerve-fibers took place as much as 5 mm. above the section; in man, however, the distance is probably greater. As the young fibers extend and divide they diverge, being separated by intervening fibrous tissue, and, growing downward, impinge upon the connective tissue, which has also grown over and inclosed the end of the nerve-stump. Being unable to penetrate so dense a mass, they become deflected and curled upon themselves and cease to grow. When, therefore, reunion of divided nerves is undertaken, these bulbous or neuromatous ends should be resected. If intervening scar tissue is not sufficiently dense to obviate penetration of the axis-cylinders in their growth downward, regeneration proceeds, and the axis-cylinders growing from the central end gradually extend to the periphery, and the nerve again assumes its normal contour, tapering from its proximal to its distal end. Tinel[73] asserts that, under favorable conditions, axis-cylinders will grow to the extent of 2 millimeters a day.

Some uncertainty still exists as to the part played in regeneration by the distal segment of the divided nerve. It was formerly regarded as capable of regenerating independently of the central connection. But now most authors, including Cone,[16] Lewis and Kirk,[42] and O. Kimura,[37] are in harmony with Rámon y Cajal,[11] who has long believed that the distal segment of a divided nerve assists in regeneration; that the nuclei of the sheaths of Schwann proliferate and have an important phagocytic function; that, besides destroying and removing débris of the degenerated nerve-fibers, they also form the sheaths that secrete a chemotactic substance capable of directing and nourishing the young axis-cylinders.

EFFECTS OF TRAUMATA

The effects of traumata upon the various structures of the peripheral nerves are essentially of the same character, although they differ widely in degree and in extent with the severity of the injury. Viewed clinically, as well as pathologically, the course of nerve injuries may be divided into three distinct periods or stages: the early stage, immediately following the injury, corresponding to that of shock; the second stage, that of healing and readjustment of function; and the third or late stage, the period of recovery or of residual paralysis. These stages vary in duration. In peripheral nerve injuries no form of shock other than true surgical shock has been constantly recognized. Cannon[12] raised the question of the relative effects of secondary wound shock upon the nervous system, and although he admits that nervous impulses may play a part in the establishment of wound shock, he believes that it is not an important one. Crile[17] believes that the nervous system bears an important relationship to wound shock. Greenman[26] observed that in rats, after section of one peroneal nerve, the fibers in the corresponding intact nerve of the opposite side were reduced in size. This

observation may or may not be germane to the subject. But the experiences of the late war justify the recognition of a clinical state comparable to the "spinal shock" of cord injuries, in which loss of function during the period immediately following the injury is more marked than the demonstrable nerve lesion could produce, even after making due allowance for complications, such as fracture of bones, severe hemorrhage, laceration, and the like.

This form of shock is not so often seen in the less severe injuries of civil practice, but was not uncommon in the more severe types of war injuries, particularly in those of the brachial plexus. The effect of suddenly cutting off the transmission of impulses by one nerve-trunk probably disturbs temporarily the functional activity of associated nerve-trunks. If, therefore, an operation must be performed during this period, evidences of structural changes in nerve-trunks not injured directly by the missile will be absent, although their function may be disturbed.

The relation of contusion and concussion of nerves to these phenomena cannot logically be denied. Gradual readjustment of function takes place in the nerve-trunks that are not sufficiently damaged to undergo complete degeneration. The fact that obvious diminution of function, particularly motor function, and perceptible alteration of structure do not always occur conjointly, may at times influence surgical judgment, particularly during the early stages. Lacerations and contusions of the tissues adjacent to and surrounding an injured nerve-trunk always accompany any penetrating wound. This is particularly true of war injuries. Infection is also generally associated. In the normal process of healing of the surrounding tissues and absorption of hemorrhage there is, therefore, marked proliferation of connective tissue, and adhesions are formed, making it difficult for a nerve-trunk, whether directly injured or not, to escape becoming embedded and constricted by masses of fibrous tissue. To promote absorption and limit the formation of adhesions as much as possible early and systematic exercise and massage are to be employed. Tight bandaging or splinting, by diminishing the blood-supply and preventing muscular movements, hinders absorption of the normally effused products, and in consequence much fibrous tissue is formed. In neglected cases the well-known ischemic paralysis results, due to fibrous changes within the atrophic muscles, intermuscular tissues, nerves, and nerve-sheaths, thickening of the blood-vessel walls, and even thrombosis may occur. Spiller[69] believes that in cases of partial recovery muscular contracture is caused by prolonged hypertonicity from excessive muscular stimulation produced by an unequal distribution of regenerated fibers, as well as by faulty posture.

Soon after the injury the nerve may be seen to have been actually severed or lacerated by a missile, but it may also be the seat of contusion or concussion. When incomplete section of a nerve occurs, only the fibers that have been divided will degenerate; those that retain their continuity do not undergo degeneration.

Dustin,[19] in discussing the systematic arrangement of fasciculi in nerve-trunks, asserts that when a nerve is only partly severed, the neural contents of every sheath that is opened undergo degeneration; hence the greater the number of subdivisions of sheaths within a nerve-trunk, the fewer are the axons that are likely to be destroyed by an incomplete lateral wound.

Not infrequently complete section occurs in the form of pseudocontinuity. The nerve then presents two swellings, situated a distance apart, the upper one being the larger; between these there is apparent continuity. Marie and Foix[46] have determined by microscopic examination that in such cases there was generally complete or nearly complete section of the nerve-fibers, and that the intervening substance, which presented the appearance of continuity, was entirely made up of fibrous tissue. These observers, therefore, advise resection of the bridge of fibrous tissue, believing that regeneration cannot take place until this is removed.

In a common type of war injury, and in one frequently encountered in civil practice as well, the continuity of the nerve is preserved, but a marked regular oblong swelling is present, caused by the overproduction of interstitial connective tissue separating the individual fibers and bundles of fibers. As a rule, the axis-cylinders have not been extensively destroyed and the proliferation of fibrous tissue has not been great, so that these cases often recover without operation. Déjerine and Mouzon[18] describe a similar type of simple induration which they assert can easily be recognized by touch, but is not visible to the eye, since there is very little swelling of the nerve-trunk. If seen soon after the injury, however, the nerve presents a congested appearance and may feel softer than normal. This type of lesion frequently involves the sciatic and median nerves, and is associated with severe pain.

Various inflammatory changes have been described in conjunction with war injuries; these include interstitial neuritis with isolated areas of inflammation, parenchymatous neuritis, vascular lesions with marked endarteritis of the smaller vessels, etc. These wounds, it must be remembered, are, as a rule, septic. The ascending neuritis of earlier writers has never been definitely shown to be a morbid process. Ample opportunities for determining this were afforded by the recent war. Sicard,[62] also Gougerot and Charpentier,[25] in a large experience with nerve injuries, were unable to find a single case of ascending neuritis. Tinel,[73] however, is inclined to accept the older views and to recognize ascending neuritis as a complication and not as a clinical entity the result of traumatism. He believes that organisms circulating in the vessels of the nerve-trunks are capable of setting up an irritation that produces severe spontaneous pain that radiates upward, as well as below the site of injury. But referred pain is a well-known clinical phenomenon, and unless there is an open and infected wound, it should not be attributed without reserve to a pathologic condition that has not yet been demonstrated as a distinct morbid process.

CONTUSION, CONCUSSION, AND PRESSURE

Contusion and pressure differ only as to whether the injury is inflicted suddenly or slowly. In cases of pure contusion capillary hemorrhage arising from the small vessels circulating between the fibers is the characteristic lesion. In severe cases alterations in the myelin sheaths occur, and actual division of fibers by crushing takes place. In simple constriction from pressure hemorrhages are less common, but alterations in the myelin substance frequently occur without section of axis-cylinders. Paralysis due to pressure without a penetrating wound is not rare, affecting, for example, the musculospiral or external popliteal nerve. In such cases the prognosis is always favorable. Occasionally even prolonged pressure does not irreparably damage a nerve, as is shown by the rapidity with which function is re-established after an operation that releases the nerve from the constriction and pressure of fibrous tissue or callus. In fact, axis-cylinders denuded of their myelin substance are incapable of functioning normally, but recovery by reconstruction of the myelin sheaths is always possible, for if the nerve-sheath has not been opened, obstruction of fibrous tissue does not occur, and much less time is required for healing than for the complete growth of new axis-cylinders.

Pure concussion is defined as a condition in which disturbance of function in a nerve is produced by the vibration and jarring of its structures by trauma in adjacent regions. Without contusion pure concussion has little justification as a distinct pathologic entity. It is conceivable that capillary hemorrhages, edema, and minor alterations of the myelin substance may be produced in this manner, although no proof of this exists.

STRETCHING AND TEARING OF NERVES

In civil as well as in military practice nerves may be severely stretched by violence, frequently in conjunction with dislocation. Occasionally, also, the brachial plexus may be torn during childbirth.

Hemorrhages within the nerve are the most constant lesions found. More severe alterations may occur. Actual rupture and tearing of the intraspinal roots which go to form the brachial plexus may result from violence. Such cases have been recorded by Mills,[49] Frazier and Skillern,[24] and Cadwalader.[9]

EFFECTS OF ALCOHOL INJECTED INTO NERVE-TRUNKS

Alcohol injected within a nerve for the relief of pain has become well established as a therapeutic measure. Alcohol destroys nerve tissues by dissolution, coagulating albuminous material, and dissolving lipoid substance, thus causing cessation of the conduction of painful sensations. Degeneration may be partial or complete, depending entirely upon the completeness of contact of the alcohol and upon the strength of the solution used. If uncomplicated, regeneration takes place in the usual manner.

Sicard[62] believes that sensory fibers are more susceptible than motor fibers to the effects of alcohol when injected. Microscopic examinations of nerves does not substantiate this theory. Alcohol affects both motor and sensory nerves in exactly the same manner and to the same degree, provided that contact is equal. After any injection the evenness of contact may not be the same in each fiber. I have shown[8] that a strong solution of alcohol produces greater destruction of fibers than do weaker solutions; thus 25 per cent. solutions produce little or no degeneration, whereas 80 per cent. solutions cause profound degenerative effects.

In certain severe cases where the painful lesion is located in inoperable situations, as, for example, deep in the floor of the pelvis or in the cauda equina, the operation of cordotomy, that is, cutting the anterolateral tract of the spinal cord, conceived by Spiller and Martin,[71] demonstrated experimentally by Cadwalader and Sweet,[10] and technically perfected by Frazier, has been most successful.

If the technic is perfect, the relief of pain by this means is permanent, since the fibers of the central nervous system are incapable of undergoing regeneration.

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CHAPTER XIX

INJURIES OF THE SPINE AND SPINAL CORD*

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With regard to *injuries of the vertebræ* the surgery of the war has added little to our previous knowledge. In the majority of cases the concomitant injury to the spinal cord has so far overshadowed that of the bones as to leave little stimulus to the study of the latter, while radiography, invaluable as it is, has greater difficulties to contend with in the case of the spine than in that of most other parts of the skeleton. With G. Richardson[1] I have recorded the results of a number of *post-mortem* examinations. The cases met with in large base hospitals seldom show crushing of the bodies of the vertebræ and, consequently, do not present the angular curvature commonly met with in the injuries of civil life. On the other hand, it is far more common to find fractures of the various processes of the vertebræ, and these are often spread over a wide area as a result either of the passage of the missile along the spine, of the general divulsive action of gunshot wounds, or, as in the ordinary fracture-dislocations of civil life, of the tearing off of processes and laminæ by traction on the muscles and ligaments attached to them. Hence, apart from the injury of direct impact, we constantly find remote cracks and fissures such as are met with in other forms of spinal injury, and these are even more widely spread in gunshot wounds than in the common forms of fracture due to overflexion of the trunk. The fractures themselves present two types: (1) the cracks and fissures already referred to, and (2) abrasions, crushings, and perforations due to direct impact and often associated with complete pulverization of the bones. In the case of cracks and fissures there is often evidence that the bone has been displaced and has recoiled toward its original position, so that the bony pressure on the cord may well have been more extensive at the moment of the wound than at any subsequent period. In many cases the bony arch of the vertebra is fractured at two points, either on the same or opposite sides of the middle line, and, as might be anticipated, the points are often diagonally opposite to one another.

All fractures may be divided into the following classes:

I. *Fractures by direct impact*:
  1. With retention of the missile:
    (*a*) In the bone.
    (*b*) In the spinal canal.
  2. With complete perforation by the missile.

* Supplementary to Chapter XXXV, Vol. II, p. 816, and Chapter CIX, Vol. VI, p. 259.

II. *Tangential injuries*:

(*a*) The missile coursing along the spine.

(*b*) The missle passing across the spine.

In Group II it is unusual to find any foreign body retained in or near the spine itself. In Group I a favorite seat for impaction is the interior of the spinal canal or the back of the vertebral bodies. Round, smooth objects, such as a shrapnel bullet, entering the theca may slip down inside it for an inch or more. In all varieties of injury there is no necessary relationship between the amount of injury inflicted upon the bones and that of the spinal cord. Minimal bony lesions may be associated with severe crushing of the nervous structures and foreign bodies may even pass between the laminæ and injure the cord without causing any fracture.

The injuries to the spinal cord in war are less uniform than in the accidents of civil life. The latter usually result from overflexion of the spine with fracture-dislocation of the vertebral bodies and a complete transverse crush of the cord at the point of angulation, the medullary injuries being very similar in all cases. In gunshot wounds, on the other hand, transverse crushes are less uniform, partial and possibly recoverable lesions are more common; the vertical extent of the injury is less sharply defined. Hemorrhage and especially sepsis are more frequently seen after gunshot injury.

The *theca spinalis* very commonly escapes injury both in fractures and in crushes of the spinal cord and is only torn when subject to direct impact of missiles or bony fragments. When torn, the edges of the wound seldom gape and it is remarkable how rare is the escape of cerebrospinal fluid from gunshot wounds as compared with that from stabs or punctures by cutting instruments. In civil life such an escape of fluid is often of diagnostic value; in gunshot wounds I do not remember to have observed it.

Hemorrhage *around* the theca is common and is often very considerable in amount. At later dates such hemorrhage is liable to be replaced by dense fibrous cicatrices, which appear to play no small part in the maintenance or even in the late evolution of symptoms of injury to the cord.

The pathologic changes met with in the *spinal cord* and its nerve roots have been fully described by Gordon Holmes[2] and others, and in this volume in Chapter XVIII by Cadwalader.

SYMPTOMS

In the great majority of cases of injury to the spinal cord the symptoms in the earliest stage are those of "spinal shock" in which all function is abolished below the lesion, with complete anesthesia and flaccid paralysis. They may be associated with symptoms resembling cerebral concussion, such as unconsciousness and subsequent vomiting, headache etc. These cerebral symptoms are transient and occur more commonly in wounds of the cervical region. They are regarded by Collier[3] as evidence that a missile has traversed the spinal canal; and

are caused by the upward impact on the medulla oblongata of a wave of displaced cerebrospinal fluid; they seldom if ever last for more than a brief period. In every case of gunshot wound, especially in those involving the bodies of the vertebræ, there is also a probability of grave if not immediately fatal injury to viscera of the thorax or abdomen and of additional shock due thereto.

Setting aside such cases, which are beyond the reach of surgery, the typical condition after any injury of the cord will, however, be at first one of flaccid paraplegia, and in this stage it is seldom if ever possible to form an opinion as to the extent of the anatomic injury. The syndrome is identical whether the cord be cut across by a missile, crushed and compressed by a missile or a bony fragment, bruised by a temporary impact (as from bony displacement with recoil), or merely concussed by the divulsive wave of a passing bullet.

In the course of a few days or even of a few hours changes may ensue that may determine the amount of injury sustained. Spinal shock passes away gradually and uninjured nerve-cells and fibers recover their activity; paralysis and anesthesia become more limited and defined and we arrive at the stage of "anatomic definition" in which it is possible more accurately to recognize the segmental level of injury or even to locate that injury to one side of the cord, as in the Brown-Séquard syndrome, which is by no means rare.

Careful studies of the reflex functions of the cord after injury by Collier[3] and by Head and Riddoch[4] have considerably modified previous teaching. Until about 1890 the classical experiments of Goltz were taken as showing that a complete transverse lesion of the cord was followed by retention or even exaggeration of reflex activity below its level. The work of Bastian and others showed, however, that in complete paralysis (generally from pressure lesions of slow onset) the "deep" reflexes were lost, and the view was accepted that the presence or reappearance of such reflexes after injury was evidence of an incomplete lesion or of some regeneration. This view was very widely although not invariably accepted, and was to a large extent confirmed by the earlier war observations. Collier laid down the following criteria for prognosis: Early reappearance of a plantar reflex, if at first lost, or a change from the flexor to the extensor type soon after the seventh day, or the presence of an extensor response earlier than this are certain indications that the lesion is partial and that some recovery will occur. Persistent loss of plantar reflex and long-standing flexor response are indications that the lesion is severe. Early return of knee- and ankle-jerk is of good prognosis. If it occur before the fourth day complete recovery will probably ensue. Return of sphincteric control is of very good prognosis.

Riddoch, examining older cases, "has shown that the clinical picture of complete division of the cord hitherto described as typical is imperfect. Under favorable conditions the portion of the spinal cord caudal to the lesion not only recovers its reflex symptoms but becomes highly excitable." He differentiates three stages of reflex excitability

after total section, viz.: (1) the stage of "spinal shock," with flaccid paralysis and loss of reflexes, toneless muscles, complete anesthesia and analgesia, retention of urine and feces, and a dry skin which readily becomes gangrenous. This condition lasts from one to three weeks and is followed by (2) the stage of reflex activity; in this stage stimulation of the sole may cause a marked flexion reflex with dorsiflexion of the toes, as insisted upon by Walshe,[5] which may involve the opposite limb; or a still more widely spread "mass reflex," in which the abdominal wall joins in the flexion, the bladder is evacuated, and sweating occurs throughout the paralyzed region; extensor reactions are also obtained from the ligamentum patellæ and tendo Achillis; in this stage the skin becomes more vascular and bed-sores tend to heal. (3) After a period of many weeks or months this stage gives place finally to a third, in which the activity of the reflex centers dies out; the extensor tendon jerks, the flexion and mass reflexes, and the automatic or reflex emptying of the bladder cease, the skin presents a strong tendency to slough, and death generally follows from septic complications.

These results, which are entirely in accordance with the physiologic work of Sherrington, are abundantly confirmed, and clearly show that the return of reflexes below the lesion is no evidence of returning function. On the other hand, Riddoch finds that in certain cases of incomplete lesion the reflexes differ from the typical "mass reflex" and conform more to a purposive type: the abdominal portion of the mass reflex (including micturition) is absent; there is a tendency to alternation of flexion with extension reflexes or to flexion of the irritated limb with contralateral extension—*i. e.*, to movements of stepping or progression. For fuller details reference must be made to the original papers. The broad issue for the surgeon lies in the proposition that the "mass reflex" usually indicates complete anatomic section, whereas in partial lesions a more purposive reflex action is observable.

Apart then from definite improvement in motor or sensory power there is in the case of the spinal cord no means of determining at *an early stage* whether an injury is complete or partial. In the great majority of cases we are thus faced by the impossibility of determining how far recovery is possible, and time alone will answer this question. All that can be done is to "place the cord in the most favorable position for repair" at the earliest possible date and then await results. For this reason it becomes almost impossible to say how far any recovery may or may not have been due to early operative treatment.

TREATMENT

In view of the difficulty of defining the extent of the anatomic lesion the question of early or late treatment by laminectomy has to be decided in the main by collateral considerations. The following propositions may, however, be regarded as almost axiomatic:

1. Other things being equal, it is unwise to operate during the stage of acute sepsis in the wound.

2. If, however, there be evidence of thecal injury with septic men-

ingitis, the best if not the only hope lies in early drainage. Little is to be expected.

3. If again there is evidence that the theca is untorn but that a foreign body or other septic mass (bone, blood, etc.) lies in its immediate vicinity, this is best removed at an early date.

4. When sepsis has ceased, if an operation is to be performed, the sooner it is performed the better.

In order to determine if possible the exact condition of the theca, the bones, and the surrounding parts the skiagram is of the utmost value, but great care is required in its interpretation. A normal position of the bones is not inconsistent with their temporary and highly effective depression. The gravest injury may be inflicted upon the cord without any fracture at all. And we find that fracture of outlying vertebral processes may be widely spread without implying equally wide-spread injury to the cord. Hence the *x*-ray picture, which should be both lateral and anteroposterior (or stereoscopic), must be compared with the probable course of the missile as indicated by the wound. In a good many cases also help has been derived from finding minute points of opacity caused by fine metallic fragments left by the missile (and especially by leaden shrapnel bullets) in their passage through or across the bones. Careful examination may enable us in many cases to arrive at a definite decision, of which the following are examples: It may be reasonably certain that the bullet has not involved the spinal canal if the wound be anterior, the metal fragments resting in a vertebral body, and the laminæ uninjured; or if the wound track lies well behind the spine and a spinous process is detached with or without metal "scrapings" at the point of fracture. On the other hand, if pictures show a metal fragment or a piece of bone inside the spinal canal we can generally assume that the cord is lacerated, severely contused, or destroyed by hemorrhage into its substance. Severe destruction of the vertebral bodies will generally imply a hopeless injury to the cord. It will often be possible, therefore, to say that an operation will be useless or, if the wound is remote from the cord, that the medullary symptoms resulted solely from concussion or from hemorrhage which may be extrathecal.

In yet other cases we may have definite indications in favor of immediate operation, as, for example, in a case of typical Brown-Séquard paralysis in which I withdrew a large pointed metal fragment from between the first and second cervical vertebræ, the base of the fragment being visible in the wound.

Such cases are, however, rare, and in war at any rate there will be little time or opportunity for their early investigation. In view of the comparative rarity of successful laminectomy under any conditions it has become almost the rule in the British Armies not to attempt early treatment. But Blair[6] points out that certain cases may advantageously be operated upon even in a C. C. S., and he gives as indications for such operations: (1) Incomplete paralysis, (2) accessibility of the missile, and (3) pain. The first of these is perhaps doubtful, as it may

well be that the case is one which, if left alone, would progress to recovery. I have felt justified in operating early upon 5 cases in which the missile was readily accessible, such operation being confined to its removal, and of these cases 2 survived and made good recoveries, while 3 died from the spread of meningitis in the torn theca. Apart from such comparatively rare cases it will be wise in the vast majority to await the healing of the wound.

Late operations, after sepsis is at an end, have been performed in many cases, but apparently not always with the same objective. The great majority of surgeons aim only at the removal of pressure, whether due to missiles, bone, hemorrhage, or cicatrices. A very few have aimed at resecting and reuniting the cord on the analogy of suture of the peripheral nerves. To this type of operation we shall return. For the present we need only consider cases of laminectomy for relief of pressure.

The largest collection of cases which I have met with is that of Marburg and Ranzl.[7] Over 300 cases were admitted to v. Eiselberg's Klinik, and of these, 142 were operated upon. The chief indication was the radiographic evidence of invasion of the spinal canal by a foreign body or a piece of bone, and operation was then adopted as soon as the patient appeared likely to survive. Operation was not, however, resorted to in cases of severe shock, certain complications on the part of thoracic and abdominal viscera, advancing bed-sores or cystitis, and septic sinuses. Apart from radiographic indications, complete paraplegia was taken as a contraindication to operation. In partial lesions improvement was awaited for two months, and any arrest of such improvement or late aggravation of symptoms was taken as an indication to operate.

Of the 142 cases operated upon, 42 had died at the time of report, 9 of the deaths being due to wound complications and 5 to pneumonia, which yields the rather high postoperative mortality of about 10 per cent. For the remaining 100 cases the following results are claimed: Little or no improvement, 59; definite improvement, 41, of which 19 were rendered fit for at least some form of military service. Of the 19 which may thus be described as recoveries, in 7 the bullet was found lodged within the dura mater, in 7 it lay inside the vertebral canal but outside the theca, and in the others there was a fracture. An excellent summary of these cases is given in the official British Medical Supplement to the Review of the Foreign Press, April, 1919.

In all of the 7 cases of recovery in which the bullet was found *within the theca* it is noticeable that the lesion was well below the level of the spinal cord; the cauda equina alone was affected; as to the propriety of the operation there can be no question, but it is not by any means certain that in at least some of the cases recovery would not have occurred without it.

In a group of 7 cases in which the missile lay *in the spinal canal but not in the theca* we again find 2 in which only the cauda equina was implicated, while in 1 there was no evidence of serious nerve injury.

Three cases are examples of unilateral lesion, and it is interesting to note how completely these recovered, an experience also shared by myself. In 1 case only was there paraplegia, and in this the bladder and rectum had escaped paralysis, so that the lesion was far from being complete.

The last group of 5 cases represents a type in which I have obtained the best results, viz., those in which the cord or cauda equina is compressed by a mass of perithecal cicatrix due to pachymeningitis; a severe example is described in the Jour. Royal Army Medical Corps, August, 1918.

Hughes[8] reports 7 cases of laminectomy, of which 4 with flaccid paralysis and sphincter loss were followed by no improvement, while 3 of late development or exaggeration of paralysis but without sphincteric loss made good recoveries.

Walton[9] sums up the selection of cases for operation as follows: In early stages do not operate unless there is some sign of recovery or the lesion is incomplete, in which case the earlier the operation is performed, the better. Symptoms developing at a late date are due to inflammatory exudation, contraction of scar tissue or callus, and operation should be performed without delay. For relief of pain operations upon nerve roots may be justifiable. Suture and grafting of the cord are useless. These words closely represent the principles which guided me throughout the war, if we add early operation for accessible foreign bodies or provision of drainage.

Having regard to the above series of observations, to many scattered reports of cases, and to our own experience, we may perhaps sum up the question of laminectomy for gunshot injuries as follows:

1. Destruction of cord tissue by section, crushing, or hemorrhage is irreparable.

2. Return of reflexes after operation is not evidence of recovery, as appears to have been thought by some surgeons who have performed suture or grafting operations.

3. Concussion and slight injuries may cause very complete paraplegia which may recover spontaneously; hence recovery after early operation is not proof of the value of such operation.

4. Early operation imports a definite risk of infection and should only be undertaken if there be a readily accessible fragment or as part of a "wound excision."

5. Drainage should, however, be provided in all cases.

6. Late evolution of symptoms is probably due to pressure, and such cases are generally benefited by operation.

7. Cases of persistent symptoms in which the spinal canal does not appear to have been directly transfixed are also liable to be associated with cicatricial pressure and are amenable to operation.

8. Injuries of the cauda equina present a greater power of repair than do those of the cord; they may almost be regarded as injuries of the peripheral nerves, and as such call for secondary operation and are even amenable to suture. Below the first lumbar vertebra all foreign

bodies should be removed from the spinal canal at the earliest possible moment.

A few attempts have been made to suture the torn spinal cord or even to insert grafts. In this connection the earlier cases of Harte and Stewart,* Fowler and Estes are sufficiently well known and it is unnecessary to return to the controversies to which they have given rise. Mayo Robson[10] refers briefly to 2 cases: (1) A case of tuberculous disease with marked angular curvature, followed by fracture, in which the cord was "torn nearly across"; the spine having been straightened, the torn cord was brought together and sutured; recovery ensued. (2) The cord was partly divided and "otherwise seriously damaged" by a bullet lodging in the spinal canal (level not stated): after sepsis had subsided the edges of the injured part of the cord were pared and a piece of rabbit's spinal cord was implanted; some recovery is stated to have occurred after two months, but the details are wanting. A third case is mentioned in which it was only intended to operate A valuable and clearly open-minded description of an attempt at suture is recorded by Claude and Lhermitte.[11] A wound in the dorsal region was followed by complete paraplegia and retention of urine. On the following day a splinter of shell with bony fragments were removed from the cord and it and the theca were sutured. Knee-jerks, defensive reflexes, automatic movements and erections returned, and were accompanied by vague sensation in the feet. After eight weeks the patient died and the cord was found completely divided with an interval of 1 cm. filled by a dense mass of cicatrix and spiculæ of bone; the cicatrix contained no nervous tissue and there was no evidence of regeneration in either end of the divided cord. The observers conclude that myelorrhapy is contraindicated, as it may give rise to complications and cannot possibly give relief. The case illustrates once more the fallacy of regarding as evidence of recovery either subjective sensations or reflex movements, however purposive.

TREATMENT OF SYMPTOMS

Pain.—Many cases of complete paralysis present severe and lasting pain which is due to irritation of the posterior nerve-roots. In some of these operation has revealed cicatricial or bony pressure or even small metal fragments which can be removed. In others, in which paraplegia is complete and permanent, it would appear that the only possible source of relief is by division of the cord above the injury.† Krauze has adopted this course, using the somewhat remarkable weapon, a Paquelin cautery, although he states that in another case he would use the knife. I have

*In the Annals of Surgery for June, 1920, will appear an important article by W. B. Cadwalader dealing with this extraordinary case nineteen years after the operation.—W. W. K.

† Instead of division of the cord, Drs. William G. Spiller, Edward Martin (Jour. Amer. Med. Assoc., 1912, 58, 1489), and Charles H. Frazier, of Philadelphia, have devised and practised in several cases with excellent results what they term *cordotomy*, *i. e.*, section of the anterolateral column of the spinal cord. The operation is fully described in Dr. Frazier's "Surgery of the Spine and the Spinal Cord."—W. W. Keen.

twice regretted not having adopted this somewhat heroic measure; I know of no case of alcohol injection into the cord, and would certainly prefer pithing as more controllable in its action.

Spasm.—Continued spasm—a prolongation of the "mass reflex"—is a source of great trouble to many patients, and in not a few cases is the main element in rendering the lower limbs quite useless. For its relief the operation of crushing the obturator nerves has been performed in the Tooting Military Hospital, and is based upon the ground that the most troublesome spasm is that of the adductor muscles. I am informed that much relief has been given by it, but no details have been published. In 2 cases Borchard and Cassirer[12] have adopted Förster's method of dividing alternate posterior roots of the cauda equina, and appear thereby to have given a good deal of relief. Riddoch[13] strongly insists on the importance during the stage of reflex activity of avoiding all rough handling, of gentleness in catheterization, and of treating digestive troubles which are liable to excite the mass reflex.

Paralysis.—Cases of complete interruption of the cord or cauda equina paralysis are, of course, permanent and irremediable, but in many cases of lesion which fall short even by a little of being complete a very remarkable amount of power may return and slow improvement may continue for a very long period of time. In all such cases, therefore, it is essential to stimulate to action such functions as remain. The use of massage and other similar methods of treatment here play their part and are conducted upon lines similar to those followed in the case of peripheral nerve injury; in some rare cases also such methods as tendon transplantation may here find a place. But injuries to the spinal cord differ fundamentally from those of nerves, in that the muscles are not cut off from the neurones or the reflex arcs with which they are directly associated, but that the latter are deprived of cerebral and cerebellar control. Hence (except in the case of those parts innervated by the actually crushed segment of cord) there is far less atrophy and degeneration, and the necessity for and value of "local stimulation" is thereby lessened. The paths which it is essential to reopen are those from the brain to the spinal segments, and the only hope of assisting such a process is by encouraging voluntary stimulation and effort. Thus, apart from the treatment of spasm, if any be present, therapeusis consists mainly in educating and exercising such muscles as remain. If the patient can use his limbs at all he should be encouraged to do so freely when in bed, and whenever possible he should be got out of bed. The self-propelled wheel chair at least tends to maintain general health and metabolism, to diminish the risk of bedsores, to allow of change and to improve the morale, while it may enable the patient to do some satisfactory work. Still better, if it can be used, is a "go-cart," in which the patient, supporting himself by the arms and axillæ, is placed inside a hollow truncated cone on wheels and makes efforts in progression with his own limbs, although these be still unable to carry the body weight. Even better is the swimming bath now largely used at Tooting; the bath is 3 ft. 6 in. in depth, is filled with water at a

temperature of 92° to 94° F., and is provided with a railing and with hanging rings or bars. In it the paraplegic man can easily support himself by his arms or by the "water wings" used in teaching children to swim, and his efforts to paddle about in the warm water are often followed by a truly remarkable recovery of partially paralyzed limbs (Buzzard[14]).

Vesical Symptoms.—That the great majority of serious injuries of the spinal cord, other than those which involve the muscles of respiration, die from the usual sequel of events—retention of urine, cystitis, urinary sepsis—is not a recent discovery. But the surgery of the war has emphasized the importance of vesical complications in several ways: (1) The transport of cases with retention of urine presented very great difficulties on account of the long intervals which often occurred between evacuations of the bladder by catheter. (2) It soon became fully recognized that cases of incomplete paraplegia presented great powers of recovery except when vesical control was lost, but that the latter symptom called for a very grave prognosis, a point strongly insisted upon by Hughes.[8] (3) Head and Riddoch[4] and others found that urinary sepsis, apart from its general bad effect upon the patient's health, prevented the return of reflex action after the stage of spinal shock and was associated with general degenerative changes in the nervous system. Such considerations led to a most careful study of the innervation of the bladder, and especially to a remarkable series of papers by Fearnsides and Head and Riddoch.[15]

In connection with treatment there arose a strong opposition to the regular use of the catheter, this opposition taking the form of: (1) Attempts to evacuate the bladder by pressure alone. (2) The permanent drainage of the bladder by cystotomy. (3) The use of the "mass reflex" to procure evacuation.

Following the late Sir Jonathan Hutchinson's suggestions of over thirty years ago, I had in the past hoped to obviate cystitis by discarding the catheter and allowing the distended bladder to overflow. The cystitis was at that time attributed to introduction of organisms by instruments, but a very short experience showed that the mere refusal of catheterization did not prevent cystitis, while at that date I discarded suprapubic and perineal cystotomy as "too heroic." These methods have, however, now become common. In many cases the bladder contents can be "expressed" by pressure upon the hypogastrium, with or without the introduction of two fingers into the rectum to produce counterpressure. Unfortunately, this simple measure, which is probably not merely mechanical, but due to stimulation of a reflex or of "idiomuscular" contraction, is by no means always effective in emptying the organ, and every surgeon accustomed to operations upon the bladder even in the absence of nervous disease knows that it cannot be expected to be so.

Suprapubic cystotomy, on the other hand, allows of very complete evacuation, of rest to the bladder wall, of immunity from all back pressure, and of efficient lavage. It has been very freely adopted in

the British Armies and with many surgeons was a routine treatment from the earliest moment after injury. The usual method as described* is as follows: "A 2-inch median incision is made and the full bladder exposed. With an ordinary sinus forceps or Spencer Wells forceps, held closed, a stab is made through the bladder wall, and then the blades are separated just widely enough to permit the introduction of a Guyon self-retaining suprapubic tube stretched on a long probe. When the forceps is removed and the probe is withdrawn the tube is found to be tightly gripped by the bladder wall and the junction to be completely water-tight." The tube is then connected with a longer rubber tube leading into a bottle attached to the bed or stretcher, and irrigation is effected by means of a Higginson syringe, the nozzle of which is introduced into the urethra. Such a method undoubtedly presented great advantages in cases requiring transport and not under the supervision of one individual, but whether in civil practice it will ultimately supplant the careful and frequent use of the catheter with lavage of the usual type is perhaps questionable.

Riddoch[13] has carefully studied the use of the "mass reflex" as a means of provoking elimination of the bladder. He points out that in the "stage of reflex activity" the bladder tends to empty itself at fixed intervals which vary in the case of the individual from two to four hours. The interval should be determined, and when evacuation is about due a flexor spasm should be evoked by stimulating the abdominal wall or the lower limbs. The bladder contents are then voided. They can be collected in a urinal and the bed is kept dry. This method of treatment, which, of course, is only available when the reflex is present, has the disadvantage that it is not possible in early cases or in those in which pyelitis has led to intoxication and abolition of the reflex, while it makes no provision for washing out the bladder. Its value will probably lie mainly in the less common and less serious cases in which cystitis has not occurred at an early date.

In my opinion it would appear that in civil practice and with good nursing the systematic use of the catheter with most careful asepsis of the instruments and of the glans penis still presents the best method of treating retention of urine, but it is always to be remembered that "the bladder holds the key to life or death for the patient," and it is impossible to exaggerate the care required in catheterization, while in military surgery the essential precautions can hardly be consistently maintained.

LESIONS OF NERVE ROOTS

It is often extremely difficult to distinguish affections of the spinal cord from associated injuries of nerve roots, and, except in the case of the cauda equina, the latter can hardly be considered apart. Hence we have already referred to such symptoms as pain which is due to affections of nerve roots rather than to that of the cord itself.

Stopford[16] describes several cases of injuries of the cervical nerve roots, dividing them into (*a*) those in which there is no lesion of the

* British official "Injuries and Diseases of War," Dec., 1917, p. 120.

cord (3 cases) and (*b*) those in which such lesion is present (2 cases). In 2 cases of unilateral injury to roots of the brachial plexus there was most marked dissociation of the sensory from the motor symptoms; a third case was bilateral and was associated with a very temporary paraplegia from concussion of the cord; the cases associated with injury of the cord showed some definite medullary affection in addition to the lesion of the root. The nature of the injury to the roots in these cases is a little obscure. The fact that they present a very rapid improvement in the extent of paralysis and anesthesia shows that much is due to concussion; the course of the bullet rendered improbable any direct laceration, which, moreover, would almost certainly have more seriously compromised the spinal cord. Hence he regards the troubles as due to hemorrhage especially from the small vessels of the pia mater; this view is also consistent with the fact that symptoms show a considerable variation even from day to day; the late supervention in some cases of spinal cord symptoms is attributed to "meningeal adhesions," *i. e.*, to the posthemorrhagic cicatrices which probably play no small part in other and graver injuries of the cord. Collier also refers to lesions of the roots due to pachymeningeal hemorrhage and periosteal hemorrhage, in which the symptoms of pressure upon the roots may overshadow those of any lesion of the cord. The diagnosis of these cases from injury of the brachial plexus may present the greatest difficulty, but can usually be effected by noting at some period a slight involvement of the spinal cord. The prognosis is very good, as might be expected from the assumed pathology and the proximity of the lesion to the trophic centers of the involved axons. Apparently the main permanent inconvenience is likely to be pain, which might call for posterior root section. These rather rare cases stand, of course, on a very different plane from those met with in civil practice in which the roots of the brachial plexus are torn away from the spinal cord, generally by abduction and elevation of the limb; in the latter injury the prognosis is almost hopeless and I have seen the most severe permanent pain following upon cicatrization, even rhizotomy being impracticable in the dense mass of intraspinal scar.

Root-lesions in the dorsal region do not appear to have been described as apart from other conditions, and, judging from the cervical cases, they would be very inconspicuous and would rapidly recover. Here, however, as elsewhere, severe pain may be due to the coincidence of such with lesion of the spinal cord.

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CHAPTER XX

INJURIES OF THE PERIPHERAL NERVES

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In the years immediately preceding the European War injuries of the peripheral nerves were a frequent subject of clinical and experimental research and obtained a due share of recognition in surgical literature, but it was very noticeable that the classical work of Mitchell, Moorehouse, and Keen, founded upon observations in the American Civil War, always held its own as the first clear exposition of the subject and was always referred to by subsequent writers. In civil life injuries of nerves are comparatively rare, and the number of cases falling within the experience of any one surgeon is never large, except in the case of those who have become recognized as taking a special interest in them. Thus it has happened that since the work of Weir Mitchell the progress of knowledge has been mainly due to experimental work.

The European War has, unfortunately, again produced an enormous number of these wounds, and it is estimated that about 20 per cent. of all serious battle casualties show some injury to important peripheral nerves. Hence, as in the American war, a large mass of clinical material has again been placed in the hands of the profession. Further, in France and in England since the first year of the war, these cases have been collected in special hospitals where the results have been noted in a way not possible in civil life. The whole subject has thus been reilluminated. To realize the advance made it is only necessary to read the reports of a meeting of the Medical Society of London held in November, 1915,[13] the observations of Benisty[1] as to the confusion of ideas and the doubts regarding treatment which obtained in France during the early months of the war, or to turn to the analysis of German literature,[12] and to contrast this chaos with the fairly well-defined rules which can now be laid down.

NATURE OF THE INJURIES RECEIVED IN WAR

The strain of campaigning during the European War has led to the evolution of affections of the nerves which might otherwise have caused little inconvenience. Thus we observed in France a considerable number of cases of compression of the brachial plexus by cervical ribs, caused by the use of the shoulder strap or other equipment. Accidental injuries were common, but differed in no way from those with which we were familiar in civil life.

Saber and bayonet wounds were comparatively rare, although accidental bayonet wounds of nerves were met with. All such cases failed to present special features. In all primary suture may reasonably be expected to be as successful as in civil life. But in gunshot wounds, including those due to bullets, shrapnel, high-explosive shells, and other weapons, the explosive or divulsive effects play a part. These gunshot wounds were met with in various proportions. It was noticeable in France that in the more open warfare after August, 1918, wounds by rifle and machine-gun bullets were more common, while those due to shell became less so. Varying conditions thus determined the nature and the prognosis of the wounds, but it is unnecessary to insist upon them from a surgical point of view save in so far as to caution the reader against general or statistical statements made from limited observations.

Referring solely to gunshot wounds, we find that these may be produced in one or other of the following ways:

1. The direct impact of a rifle or machine-gun bullet of high velocity. Here the injury approximates to a clean section; sepsis is comparatively slight or may even be absent; gas gangrene is rare; the nerve may be merely perforated or may be cut across in part only; where section is complete the ends are seldom far apart, although the divulsive action of the bullet causes injury more widely spread than that of section by a cutting instrument.

2. The impact of fragments of shell, of shrapnel bullets, and of other missiles of comparatively low velocity but often of considerable mass causes wounds of greater extent than those due to bullets. The nerve may be contused or crushed without loss of mechanical continuity; it may be torn through, its ends being often widely separated; a section of it may be entirely blown away. Sepsis is more severe and gangrene more common than in the last case.

3. Indirect injury may be due to the scattering of fragments of bone; here the mechanical injury tends to be less than in the second group, but sepsis is generally severe.

4. Concussions may arise without any direct impact of metal or bone and may result merely from the displacement of soft parts. In slighter cases described as concussion there may be no discoverable anatomic change and loss of conductivity is usually soon repaired.

5. Cicatrices and occasionally bony callus or aneurysms may give rise to compression at a date subsequent to the original wound.

The conditions produced at the time of injury may thus consist of complete section, with more or less wide separation of the cut ends, such complete section being found in only 22 per cent. of all cases which reach base hospitals (Benisty[2]); of partial section, in which some fibers only are divided by "attrition," while the rest of the nerve is anatomically intact but often full of blood-clot; of hemorrhage into the nerve substance without loss of continuity (contusion); or finally, without obvious change, physiologic continuity is completely interrupted. In very many cases of contusion there is only local destruction of axis-

cylinders without complete degeneration, and therefore a capacity for early repair; in not a few—in which physiologic interruption is only temporary—not even microscopic changes have been discovered (concussion).

More important for the surgeon are the local conditions met with after a month or two, when secondary operations may be required and when it is essential to know whether the injured nerve is or is not capable of spontaneous recovery; in such cases we may meet with:

1. Complete separation of the two ends of the nerve with a varying interval.

2. A similar condition in which the two end-bulbs are held together by a band of cicatricial tissue.

3. Partial section with a distinct lateral notch showing bulbous formation, especially on the proximal side, and often cicatricial changes in the uncut portion of the nerve.

4. Partial section or perforation with a fibrous nodule, which may be central and which is again liable to accompanying sclerosis. In the two latter cases there is no complete anatomic separation, but physiologic loss of continuity may be complete or partial.

5. No form of mechanical division, but sclerotic changes with local degeneration of nerve-fibers.

6. In some cases foreign bodies, as metal fragments or pieces of bone, may intervene between the ends of wholly or partially divided nerves.

7. In cases of compression the nerve is impinged upon or surrounded by cicatrices, callus, or the wall of a traumatic aneurysm, and in such cases it may be much thinned and is often very sharply strangulated.

SYMPTOMS OF COMPLETE SOLUTION OF CONTINUITY

Surgeons and neurologists have endeavored to distinguish signs by which it would be possible to recognize at an early date those injuries of nerves in which loss of function is accompanied by such anatomic changes as to indicate operation, and those in which repair might be expected to ensue after a reasonable period without operation*; but it is now generally recognized that time alone will indicate whether recovery is or is not possible. A syndrome of permanent and a syndrome of temporary lesions cannot be differentiated early, so we must fall back upon a syndrome of complete interruption of physiologic continuity and a syndrome of repair, the prognosis depending upon repeated examinations to detect the transition from the first to the second. In the slightest cases this transition may set in after a few days or it may be delayed for months.

The details of the respective syndromes have been carefully studied by Déjerine and Pierre Marie with their pupils.[15]

Complete loss of function may result not only from section of a nerve but also temporarily from severe bruising, with hemorrhage and

* This is referred to by Cadwalader in the chapter of this volume on The Pathology of Gunshot Wounds and Other Severe Injuries of the Nervous System.

intraneural scar formation, or even from mere concussion without obvious anatomic change and by shock. (See chapter on The Pathology of Gunshot Wounds and Other Severe Injuries of the Nervous System by Cadwalader.) The symptoms to be considered are motor paralysis, myotonic, myotrophic, postural, and electric alterations, and sensory, vasomotor, secretory, and trophic changes.

1. **Motor Symptoms.**—Paralysis has been sufficiently dealt with in Volume II of this work. It is always present from the outset except in purely sensory nerves. Spasm is evidence of incomplete interruption of continuity. The extent of paralysis cannot, however, be assumed from mere limitation of joint and other gross movements; to establish this we must examine each individual muscle for traces of voluntary contraction. In some cases the preservation of faradic contractility will be a sufficient indication that paralysis is not profound. It must also be borne in mind that motor fibers may run an irregular anatomic course, thus the flexor brevis pollicis may be supplied by the ulnar instead of by the median nerve; such peculiarities have given rise to frequent errors.

Gross movements, such as those of joints, are more readily recorded by some form of goniometer or by registering the position of limbs by means of molded strips of lead. In many cases of paralysis the efforts to move may lead to contraction of opposing muscles—a condition often seen in injury of the musculospiral nerve.

With paralysis is found complete atony of the affected muscles, readily appreciated by the observer's hand, especially in the upper limb. This loss of tone is decidedly more marked in cases of complete solution of continuity than in incomplete lesions.

Atrophy of muscle usually follows two or three weeks after the injury and, like atony, is more marked after section than in compression, although in neither does it reach the degree often observed in irritative lesions. It is particularly noticeable in the ulnar nerve, the wasting of the abductor indicis and of the hypothenar eminence is obvious. The deltoid, biceps brachii, supinator longus, and large thigh muscles also show early atrophic changes.

In the presence of paralysis and hypotonia gravitation and the opposing muscles have free play, and hence result special attitudes which are often characteristic, as in the "claw-hand" of ulnar paralysis, the "ape-hand" of lesions of the median, the "wrist-drop" of musculospiral lesions, "drop-foot" in those of the external popliteal, wry-neck in lesion of the spinal accessory, etc. In all cases the abnormal posture tends to be more marked in cases of complete anatomic nerve section than in those of compression. These postural changes are of extreme importance, as they cause stretching of paralyzed muscles, with contraction of their antagonists and ultimately changes in fibrous tissues, especially in ligaments, which render recovery of function impossible, even if at a later date the affected nerve be completely repaired. The insistence by Sherren, Robert Jones, and others on the importance of preventing such deformities from the earliest moment by suitable

splinting, etc., has done much to improve the prognosis of injuries of the nerves (p. 549).

The **electric reactions** of nerve and muscle have been carefully studied during the last few years and many obscurities have been cleared up. The whole question is admirably dealt with by Tinel and in various papers, especially those of French physicians and physiologists.[16] For the surgeon, however, it presents complexities of investigation which should lead him to ask for assistance from a specialist. Briefly, in complete interruption, the reaction of both nerve and muscle to the faradic current is lost in a few days; the typical R. D. appears in the muscles about the tenth day and may be identical in both anatomic and physiologic loss of continuity; its most marked character is slowness of the contraction rather than polar inversion; the paralyzed muscles show an increase of excitability when stimulated at their lower ends rather than when attacked at the motor points (longitudinal hyperexcitability), *i. e.*, the muscle-fibers are hyperexcitable to galvanism, while the nerve has lost its capacity to react either to galvanism or faradism. In old cases all forms of galvanic excitability ultimately disappear after a period of eight or ten months. Such an end-result may usually be taken as indicative that the body of the muscle is completely fibroid and that no contractile tissue remains.

In association with electric changes we may note the tendency of paralyzed muscles to idiomuscular contraction which is often well defined. Such contractions are readily provoked by mechanical stimulation of the muscular fibers, and they are very noticeable in separating the fibers of the triceps muscle to obtain access to the musculospiral nerve. They are met with in all forms of peripheral injury and may be well defined even if hypotonia is complete, but they disappear at a later date in association with the complete loss of contractile tissue. (It is not impossible that much of the value of massage lies in its power of evoking such idiomuscular contractions and thereby providing a vigorous local stimulation.)

2. **Sensory changes** in complete lesions are well defined from the moment of injury to the nerve, but in the first few days anesthesia tends to diminish slightly, owing probably to a rise in the activity of overlapping fibers from adjacent nerves. There then ensues a typical picture which has been described by Rivers, Sherren, and Head.[17] From these observations it appears that there are at least three distinct types or varieties of sensory conduction,* the loss of each giving rise to a distinct type of anesthesia: 1. "Epicritic" sensation records light touches, as with cotton-wool or a piece of paper (which must be used lightly so as not to depress the skin), minor degrees of variation in temperature and fine localizations, as indicated by the discrimination of two points of a pair of blunt compasses or the esthesiometer. 2. "Protopathic" sensation records painful stimuli such as pin-pricks, and

* It by no means follows that there is any differentiation of the conducting fibers or end organs, and although for convenience we may speak of epicritic and protopathic fibers, their separate existence is not yet proved.

appears to be specially concerned in initiating reflex movements, but has little power of localization. 3. A deep series of afferent fibers conducts such impulses as heavy pressure or vibration (tested by the tuning-fork) and records the position and movements of the bones, joints, and muscles, as well as the pain associated with deep pressure. Epicritic anesthesia corresponds in area with that of the recognized anatomic distribution of the nerve and the so-called epicritic fibers overlap very slightly with those of adjacent nerves. The protopathic series of afferent fibers have a wider overlap, and hence, as adjacent nerves carry on this function, protopathic anesthesia is generally less extensive than is epicritic; roughly, the area of protopathic anesthesia corresponds to that in which pain is felt when the nerve is irritated.

3. **Vasomotor, secretory,** and **trophic changes** are less well marked in cases of interruption of continuity than in those of nerve irritation, but they are, nevertheless, generally present. Most obvious upon the hand and foot, they are also observable throughout the limbs, but are hardly recognizable in cases of injury to the nerves of the trunk. The classical picture is one of coldness, accumulation of epidermis, dryness, and vascular irritability, shown by persistence of red streaks after scratching, ready bleeding after a prick, and a tendency to blistering and ulceration after trauma, especially from heat and cold, which are, of course, not felt in the anesthetic area. The most convenient explanation, at least for mnemonic purposes, is that the separation of local vasomotor mechanisms from central control is followed by excess of their activity, but that on irritation they are readily upset and vascular contraction gives place to dilatation. In very old cases of paralysis the fingers and toes become dry and tapering, with loss of subcutaneous tissue.

Changes in the nails and hair also occur. The nails become dull, brittle, and curved, often with longitudinal or transverse striation, their growth is unduly slow, a condition attributable to lack of movement (Head and Sherren). Hairs may change their color, become brittle, and are irregularly arranged.

Bone may show atrophic changes, but there is no evidence that this is due to any influence other than disuse; fractures in paralyzed areas appear to unite normally. Joints, especially those of the fingers, show thickening and contraction of their ligaments and even intra-articular fibrosis, but here again immobility probably plays a large part. Acute joint troubles do not arise unless complicated by sepsis. It is hardly necessary to point out that in gunshot wounds the picture is often complicated by lesions of blood-vessels, bones, and joints, as well as by suppuration, cicatrization, and resulting contractions. A gunshot fracture of a long bone is apt to cause osteomyelitis far beyond its obvious limits as well as effusion into neighboring large joints, and such conditions must not be too readily assigned to loss of nerve supply.

It will thus be seen that in complete loss of conductivity secretory and trophic troubles are mainly conspicuous by their absence, and

when present are usually due to associated conditions. They are far more characteristic of incomplete and irritative lesions.

According to the school of Déjerine the following group of symptoms indicates complete loss of continuity, whether due to gross separation of the nerve ends, to intervening cicatrix, or to other conditions calling for surgical treatment.

1. **Muscular Symptoms.**—Complete paralysis of all muscles supplied by the nerve, complete loss of tone, as shown by palpation and attitude, absence of all pain on pressure over the muscular masses, atrophy, typical reaction of degeneration.

2. **Sensory Symptoms.**—Absence of any area of paresthesia or hyperesthesia in the territory concerned, absence of pain on pressure on the nerve trunk below the lesions, fixity of the various types of anesthesia already described. This syndrome differs from that of compression, even if very complete, in the intensity or precision of the symptoms, in the absence of any tenderness in the muscles or distal nerve trunk, and especially in the fact that in compression sensory symptoms are, as a rule, less well defined. It differs from the syndrome of recovery in that in the latter we find spontaneous pain, pain on pressure over the nerve trunk distally to the lesion, diminishing areas of anesthesia, and the appearance of paresthesia and a return of muscular tone.

In opposition to this apparently simple view it is, however, pointed out by Meige, Pitres, and others that the whole of the Déjerine-Mouzan syndrome of interruption may be followed by recovery without operation, and that such minor injuries as contusions and concussions may produce all the above symptoms. This is the experience of most surgeons. Hence it is of importance to examine all cases at frequent intervals for a period of several months, and to note changes which occur and which point toward return of function.

SYNDROME OF RECOVERY AFTER LOSS OF CONTINUITY

The first reliable indication of return of motor power is usually an improvement in muscular tone as felt by the observer, although this may be preceded by a subjective sensation that the limb feels "more life in it" or "feels different." Atrophy now ceases to progress and improvement in bulk as well as in firmness of the muscle both precede any contraction. The first sign of voluntary movement is a thickening of the body of the muscle on effort, and this often precedes demonstrable contraction in length. Restoration of voluntary muscular movement may be long delayed and is at first often clumsy and uncontrolled. In the case of the musculospiral nerve, which is most readily susceptible of observation, this lack of control is especially noticeable, and is attributed by Thomas[18] to "erreur d'aiguillage," or error in shunting from imperfect coaptation of down-growing axons with their new peripheral conducting tubes. In some cases motor recovery is associated for a time with spasm, which Thomas attributes to the irritation of sensory fibers by efferent impulses from shunting of efferent into af-

ferent tracks, or vice versa. The date of restoration of electric reactions as compared with that of voluntary movement is most variable. As a rule—but it is one with many exceptions—voluntary contractility precedes the return of faradic excitability of the nerve. In the majority of cases the nerve begins to react to faradic currents before the muscle. Polar inversion gives place to equality, and finally, but after very varying intervals, to a normal galvanic reaction.

The date at which voluntary motor power may return varies enormously and is determined by the nature of the lesion, by the individuality of the nerve (*infra*), and also by the distance of the lesion from the end organs to which new axons have to penetrate. In cases of concussion complete recovery may occur in a few days, if not hours. After severe compression with the syndrome of total interruption relief of compression may be followed by some restoration of motor power within a week, and such restoration may be complete within a few months even when paralysis and atrophy have been present for many months. In cases of complete section recovery is much more slow. It is estimated that regenerating axis-cylinders grow at a rate of 1 mm. per diem, or in very favorable circumstances at double that rate (Tinel). Thus we must allow say two hundred days for fibers to grow from the wrist to the tip of the middle finger, or two years from the middle of the thigh to the foot. To this has to be added time required for the repair of end organs, for education of badly shunted fibers, and for recovery from atrophy, or, in neglected cases, from contractures. Fortunately, actual observation reduces somewhat these theoretic figures, and it is also found that the time required for repair does not vary so directly as was formerly thought with the length of peripheral nerve to be traversed. But there is a wide variation in different nerves: the musculospiral recovers comparatively rapidly, the ulnar nerve less so, and the sciatic and median with extreme slowness (Benisty, Meige), it being very noticeable that restoration of function in the case of small and highly specialized muscles, such as those of the hand, is a much more tedious process than is the recovery of the more massive groups which serve the larger joints.

In 1600 cases of peripheral nerve injury studied in Manchester by Stopford it was shown that in 60 cases of secondary suture of the musculospiral the time required before the first sign of recovery varies as follows with the site of the lesion:

Lower third of upper arm	four to five months
Middle third of upper arm	five to six months
Upper third of upper arm	seven to eight months

In 39 cases of injury of the median nerve the action of the abductor pollicis was taken as the most reliable indication of restoration of continuity, and, in order to obtain uniformity, observations were limited to eighteen months after secondary suture. In such injuries in the lower third of the forearm protopathic sensation began to return in three to four months, the abductor brevis pollicis had recovered in 10 out

of 24 cases. In injury at the bend of the elbow the pronator teres and flexor carpi radialis began to recover in four months; the abductor brevis had recovered in 2 out of 8 cases. In injury to the upper arm, the pronator teres, flexor carpi radialis, and palmaris longus began to recover in six months; the abductor brevis had recovered in 2 out of 7 cases. Sensation was rarely restored in the index-finger.

After suture of the sciatic nerve (37 cases) the first signs of recovery were noted at the following dates: protopathic sensibility, four months; gastrocnemius, five to six months; tibialis anticus, seven months; extensor longus digitorum, eleven months; extensor longus hallucis, fourteen months. In 27 cases of secondary suture of the external popliteal nerve the dates were as follows: protopathic sensibility, three months; tibialis anticus, five months; peronei, five to six months; extensor longus digitorum, seven months.

The restoration of sensory function was most carefully observed in Head's personal experiment. After section and immediate suture of the radial nerve at its point of origin from the musculospiral, with simultaneous section of the external cutaneous just above the separation of its two branches destined for the outer side of the forearm,* both epicritic and protopathic loss of sensation remained for about fifty days, after which protopathic sensation began to reappear. After four months sensation to pin-prick began to return in the area of protopathic loss. Only after two or three years was perfect sensation restored so as to allow normal appreciation of temperature and of the distance between points of the compasses.

According to Thomas[19] and Belenki,[20] one of the earliest signs of sensory recovery is pain on pinching of the skin so as to affect both cutaneous and subcutaneous tissues, and shortly afterward is noticed the sensation of "fourmillement de restauration" or tingling of repair (Létiévent, Tinel), evoked by pressure on the nerve trunk below the level of the lesion. Tinel in particular has most carefully investigated this condition, which is often spoken of as "Tinel's sign." It is described by patients as resembling the passage of a galvanic current. Such a sensation is often produced by pressure or tapping the nerve *at* the site of the lesion, in which case it has no value as a sign of repair and is rather to be taken as indicative of a stationary condition, but if it can be excited by percussion or pressure *below* the lesion it proves that at least some repair is in progress. In brief, formication is produced, and produced only when we press upon or percuss a point where there are actively growing axis-cylinders.

It is also to be noted that pain on deep pinching and formication is often followed by some pain in the muscles, especially when massaged, a condition again assigned by Thomas to an error in shunting, afferent axis-cylinders having grown down into peripheral motor channels.

* It is to be noted that most Continental writers apply the term "radial" to what is called in England the musculospiral nerve, as well as to its sensory terminal section in the forearm, which alone is called "radial" in England.

Lastly, we may note that deep sensation (vibration, bones, joints—see above) is restored at a very late date and probably not until the period of complete restoration of epicritic sensation, but it must be reiterated that the afferent fibers for such sensation run in motor and not in sensory nerves.

THE TREATMENT OF INJURIES PRODUCING LOSS OF CONTINUITY

The treatment of injuries of peripheral nerves may conveniently be considered under the headings of:

1. Primary suture.
2. Secondary suture.
3. "Expectant" treatment either during recovery or while awaiting operation.
4. Orthopedic and educational treatment after partial or complete recovery.
5. Plastic operations for incurable paralysis.

1. That primary suture of divided nerves is the ideal method of treatment is not disputed, but in war wounds it is seldom practicable. In the free excision of wounds required in France large nerves were often exposed. When uninjured they should always be respected, which can generally be done without interference with drainage and with good hopes of their recovery. When divided the ends should be brought as near together as possible by a single catgut suture. In war wounds sepsis is always present and attempts at elaborate suturing or removal of damaged nerve ends is useless, merely resulting in the ultimate destruction of more of the nerve trunk. Stabs and cuts, on the other hand, should always be dealt with by careful primary suture.

2. In determining indications for secondary suture there is great difficulty, but certain data may be regarded as established.

(*a*) Such operations should not be undertaken in the presence of infection.

(*b*) After obvious infection has ceased there remains a period of latent infection during which operation is liable to re-excite an active process. This period is of uncertain duration, but probably seldom or never exceeds two months; it is much shorter in wounds of soft parts than in those of bone, and operations undertaken with impunity upon nerves have been followed by sepsis from a later operation upon bone (Platt). Goadby[21] has shown that latent infection is generally due to anaërobic organisms, but that gas gangrene rarely reappears, whereas streptococcal reinvasion is common; hence he advises the previous use of a polyvalent streptococcal vaccine, and he found that the percentage of recrudescent inflammation was much diminished thereby. Massage of the cicatrix is helpful, for if inflammation follows it, operation must be postponed.[22]

(*c*) Secondary operation should not be undertaken until there is a reasonable certainty that spontaneous recovery will not ensue.

(*d*) On the other hand, undue delay is unwise because it may increase the risk of failure. Nevertheless, satisfactory results have been

obtained from operations undertaken a year or more after the injury. The estimation of the delay necessary to allow for signs of recovery to appear is arbitrary, and varies from two to six months, but the majority of surgeons are perhaps in favor of the shorter of these two extremes.

(*e*) As to the prospect of recovery without operation statistical observations are not of great value, the conditions being too complex to allow of any reliable estimate being formed. Tinel estimates that 60 to 70 per cent. of all nerve injuries recover spontaneously, but that 10 to 20 per cent. of these would have gained by operation, and that in all 30 to 40 per cent. of cases of grave injury will eventually require operation.

(*f*) Secondary suture may be contraindicated by grave complications, such as ununited fractures, seriously damaged joints, great loss of muscle or wounds of such extent as to show that very large pieces of nerve have been removed. In such cases amputation will generally be called for.

If an operation is decided upon it must always be regarded as primarily exploratory, and its final nature will depend upon the conditions found, but again, certain general principles must be adhered to in every case. A general anesthetic will usually be required. The most rigid asepsis is essential. Incisions should, as far as possible, avoid going through old scar tissue, which is liable to latent infections. Hemorrhage should be most carefully arrested and, if the wound is not perfectly dry, drainage should be provided for twenty-four hours. The use of a tourniquet is disputed: it greatly facilitates difficult dissection, but it must never be used unless it can be placed so far above the wound as not to interfere with any needful stretching of the nerve; the objection that it causes delayed flushing of the wound with blood appears to be exaggerated, and this difficulty can be met by its removal immediately after the nerve ends have been exposed or by drainage. Kennedy[23] strongly urges its use to save manipulation. Platt condemns it as having caused pressure paralysis, but such a result merely indicates that it has been too tightly applied.

With such precautions the nerve ends are exposed by means of a long free incision which may even call for transverse incision of such muscles as the gluteus maximus, the detachment of shoulder muscles, or resection of the clavicle. It will then be necessary to decide whether resection or other proceeding is to be adopted. Where the ends lie apart, resection and suture or even grafting may be required, but it is more common to find the ends held together by a cicatrix, or to discover a lateral or central pseudoneuroma in the course of an incompletely divided nerve. When there is a doubt as to how far a cicatrix is penetrable by axis-cylinders, methods of local investigation have to be adopted. Meige employs the bipolar faradic exciter (*supra*) to determine by stimulation of the proximal end whether any continuity persists through the scar. Platt and Brentnall[24] describe a simple apparatus for this purpose: Two ordinary silver probes are sharpened to a point, each is enclosed in rubber tubing, and they are then lashed to-

gether by linen thread kept taut with a wooden wedge; each probe is attached to terminals of the Bristow coil and a minimal current is employed. The instrument, having been boiled and carefully dried, is of value in all operations to determine the conductivity of the doubtful trunk, the destination of muscular branches, and also whether any doubtful bands of tissue are nervous or cicatricial. Daw[5] recommends the following method of using a bipolar exciter, viz., first stimulate the peripheral end; if the muscles react, there is no degeneration; then stimulate the central end, if there is no reaction there is a block at the lesion, but so long as there is no degeneration below, recovery is possible; if no reaction is obtained either above or below, there is a complete block with degeneration, and resection is essential.

Whenever it has been decided to resect and suture the nerve, the following precautions should be adopted: All dissection must be completed before resection is attempted, all cicatrices must be thoroughly divided, and cicatricial tissue removed as far as possible; the nerve should be fully laid bare, and if necessary the gloved finger may then be introduced into the wound to sweep round and free a large nerve, such as the sciatic. Apart from this the hands should be kept out of the wound. The nerve must be treated with the utmost gentleness and can be held by forceps only at the ends which are to be resected. The trunk, if necessary, may be held up by blunt hooks, loops of drainage tubing, or of gauze. The limb must then be adjusted in such a position as to give full relaxation, and it will be decided whether it is advisable to alter the position of the nerve so as to gain still further relaxation. This procedure is often adopted in the case of the ulnar, which can readily be transplanted from the back to the front of the internal condyle when flexion of the elbow will shorten its course by several inches, but it is doubtful whether such transplantation is not harmful (it may injure the branch to the flexor carpi ulnaris), and it is better to obtain relaxation by strong flexion of the elbow and wrist, with adduction of the arm (Souttar and Twining). The musculospiral nerve can also be placed in a shorter and more direct bed by transplantation to the inner side of the humerus, bringing it across the front of the elbow-joint, but the gain in distance is here extremely slight. Only after all such proceedings are completed must resection be commenced.

At this stage may be employed an ingenious instrument introduced by Babcock.[25] This consists of a pair of calipers with a fine screw adjustment, to the ends of which two lace-pins can be attached. The nerve is transfixed by the two pins at a distance of 2 to 3 cm. above and below the area to be resected, the sharp ends of the pins being held in slots on the blades of the calipers. On closing the latter the nerve is stretched, the ends are approximated and steadied, while, incidentally, rotation of the trunk and consequent "bad shunting" is prevented. It is stated that the pins rarely cut out and that they inflict no more damage than the tension suture which is often required, while their steady traction helps greatly to approximate the cut ends.

In some cases a method of two-stage operation has been adopted:

the nerve ends having been exposed and approximation regarded as impracticable, the best postural position is secured and the ends tied together by a ligature; at the end of three weeks they are again exposed, and it will be found that they have elongated considerably and that end-to-end suture can be effected. Posture alone allows of stretching the sciatic over a gap of 5 inches, and by this method an even greater distance can be covered.

The actual resection is carried out with a very sharp knife or a Gillette razor blade. The upper neuroma is shaved away until bundles of nerve-fibrils are well seen; the peripheral end is cut off below any obvious fibrous cicatrix. Daw suggests that such resection should at first be carried only two-thirds of the distance through each end, the gap being closed at one side before resection is completed. With Babcock's calipers this is unnecessary.

For suture the finest needles should be employed, and most surgeons will agree that catgut should alone be used. The catgut should be prepared by boiling in xylol and should not contain iodin or other irritant chemicals. If the needle be threaded with the dry gut as soon as it is taken out of the xylol it will be found much easier to pass through a fine eye. Some surgeons employ silk or horsehair (Kennedy), which has the advantage of being easy to work with and of passing through a very fine needle eye, but we strongly prefer an absorbable medium. As to the method of suture, transfixion of the nerve by a single thread will suffice for smaller branches, but for all large trunks it is far better to use a continuous circular suture or a number of sutures passing through the sheath only. The cut ends must be brought into contact, but the suture must not be drawn so tightly as to evert the nerve-fibers (Nageotte); of the extremes, it would be wiser to leave a short gap.

Suture being completed, there will arise the question of surrounding the junction by some covering destined to prevent adhesions and to obviate the spreading out of axis-cylinders. The tendency of recent work lies in the direction of avoiding all such coverings. If used at all, strips of fat (autogenetic) will probably be best, but Cargile membrane is very convenient. In cases in which all scar cannot be exsected Platt prefers a muscle bed to any other form of covering.

The wound should be drained if there is any doubt as to its complete dryness, and the limb is fixed in the position of relaxation. Souttar and Twining remove all restraint after seven to ten days, trusting to residual stiffness to last for about an equal period and to union being sufficient to withstand all voluntary effort after, say, three weeks.

In cases of lateral or central neuroma or of lateral notches on nerves exactly similar proceedings are adopted, but they are limited to the damaged segment, the uncut fibers of the rest of the nerve being allowed to fold up and retain their continuity. In such cases the faradic exciter may be of great value in determining how much of the thickness of the nerve requires resection. It is always to be remembered that *mere* resection of a neuroma is useless without end-to-end suture of the freshened nerve ends.

There remain for consideration those cases in which after effective resection and complete removal of cicatrix the nerve ends cannot be brought together even after adjustment of the limb, a "two-stage" operation or transplantation of the trunk. Such cases are not numerous, but present very great difficulty. The older methods are described in Volume II, *i. e.*, splitting and turning down the end bulbs, implantation into an adjacent nerve, and the use of decalcified bone, etc. All fail.

In nerve grafting we aim at introducing a piece of new nerve in which the axis-cylinders die, leaving channels open to penetration by the axons of the proximal end; direct continuity is thus aimed at and is essential. The graft has almost invariably been taken from a healthy nerve of the patient (autogenous grafting); it will rarely be practicable to provide it from the amputated limb of another human being; heterogenous grafts from animals do not give good results. As donor nerves the radial in the forearm, the musculocutaneous in the leg, or the internal saphenous in the thigh are usually employed, as their resection involves no paralysis and it may be possible after having removed a sufficient amount for the purpose of the graft so to stretch the donor nerve as to effect a primary suture. With large nerves the diameter of the graft is generally too small for the gap, and then it is necessary to use two or even more pieces side by side, but in every case the length implanted must be sufficient to bridge the gap without trace of tension. In all other respects the methods of operation are identical with those of ordinary secondary suture.

Prognosis and Results.—From time to time statistical papers have given the results of suture and grafting of nerves after war injuries, the more important being those of Tinel and Adison,[26] Kennedy,[27] Dumas,[28] Joyce, Souttar, Jocelyn Swan, and Welby Fisher. The British Medical Research Committee whose report is not yet available in detail has carefully investigated a large number of cases operated upon. In the case of nerve grafting they have not met with one case of complete recovery and but very few partial recoveries. Most cases have ended in failure. Bridging by catgut, vein, alcoholized nerve, and other foreign material has consistently failed. The turning down of flaps of nerve, and nerve-crossing or anastomosis—that is, implanting the distal end of the divided nerve into a healthy one—invariably fails. The conclusion come to is that end-to-end suture by a one- or, if necessary, a two-stage operation is the method to be adopted in every case.

The prognosis can be summarized as follows: The prognosis as regards functional utility after nerve suture depends very largely upon which particular nerve has been injured. Thus the musculospiral usually makes a good recovery, while the ulnar, as regards the intrinsic muscles of the hand, does badly. Another factor of importance in prognosis is the occupation of the patient. A man with an ulnar nerve lesion will usually recover both sensation and muscular control quite sufficient for most trades, but he will not recover control of the finer movements of the hand, such as are needed for piano playing.

After the musculospiral, in order of good recoveries, we must place the sciatic. The brachial plexus often makes a good recovery, especially the upper part.

Median injuries do fairly well, the thumb intrinsics even recovering in some cases, while it is usual for the wrist flexors and considerable sensation to recover. Sensation, however, is usually lost, or very slowly or rarely recovered from, over the terminal phalanx of the index-fingers.

The ulnar recoveries are good as regards wrist and finger reflexors, and even its sensory disturbance clears up well. As has been stated, good recovery of the interossei is very rare. They may and do recover their faradic excitability more often than voluntary power.

Combined lesions of the median and ulnar, particularly if complicated by ligation of the artery, do very badly. There is usually the stiff, rigid, board-like hand with joint changes to still further hinder the chance of good function. This is, indeed, the important obstacle.

3. **Expectant Treatment.**—In all cases of section there will be a waiting period either while recovery is hoped for or until the best time for operation has matured, or after operation while awaiting return of function. During this period it is essential that in all cases the stretching of paralyzed muscles and postural deformities already referred to should be prevented by suitable apparatus (Sherren, R. Jones, etc.). Wrist-drop is counterbalanced by a hyperextension splint, drop-foot by an elastic muscle or other similar apparatus, paralysis of the deltoid and flexors of the elbow by putting up the shoulder in an abducted position, with the elbow in inflexion, generally with supination. Splinting of median and ulnar nerve injuries is difficult and seldom necessary, but for the ulnar it may be advisable to use at night a palmar splint which slightly adducts the fingers, flexing the metacarpophalangeal joint and extending the interphalangeal. According to Robert Jones[29] relaxation of paralyzed muscles must be absolutely continuous and a single act of stretching may be regarded as undoing the work of weeks of splinting, but the majority of observers take a less extreme view and prefer to obtain full daily movement of joints while maintaining fixation at other times.

Almost equally important is stimulation of the circulation by massage and electricity with movement of joints liable to stiffness or contraction. Care is required in removing splints and the masseur must hold or support the limb throughout the process. For example, with a paralyzed musculospiral nerve the wrist and fingers as a whole are supported in the hyperextended position, and each joint is then separately flexed, while others actuated by the same tendon are hyperextended. For support in such a case we may use a cock-up palmar splint which hyperextends the wrist only, but which carries a terminal metal loop to which are attached rubber loops for each digit, that for the thumb being placed in an abducted position; flexion of the digits is then possible by voluntary effort, but the position of rest remains one of hyperextension. In no case must massage be employed over cica-

trices in which septic infection might thereby be relighted. In passive motion of the fingers the wrist should never be flexed at the same time.

Electric stimulation of muscles is also of value for improving circulation and causing contraction of the bellies of paralyzed muscles, but there is little if any evidence to show that it hastens regeneration of the nerve, although such action is claimed for it by some writers. Only the mildest effective current should be used and care must be taken not to stimulate non-paralyzed muscles. If any reaction is obtainable with the faradic current then the Bristow coil is best adapted; one pole applied to an indifferent point and one to the affected muscle, or the distal pole may be in the form of a roller or the hand of the masseur is connected to the battery by a wrist strap. When the faradic current gives no response a mild galvanic current may be used with a metronome interrupter acting once in every second. A few contractions daily will suffice for each muscle.

In many cases where postural deformities are well defined but splinting is difficult or impracticable we must combine with massage and electricity the valuable effects of voluntary effort and education. Patients should be encouraged to use a paralyzed hand from the earliest possible moment, and the orthopedic and educational measures referred to below should be commenced as soon as the wound allows. The added moral value of such action needs no insistence.

An additional aid to local recovery is warmth. The parts should be covered by gloves, sleeves, etc., which serve the added purpose of preventing injury to the anesthetic areas. The whirlpool bath and baths of warm paraffin wax, which is allowed to dry and form a complete covering, are also useful. The whirlpool bath has been found very valuable throughout the war; it is stimulating, economic of hot water, and has reduced the time required for massage from thirty to ten minutes (Souttar and Twining). All movements can best be effected in warm water, and the patient should practise using his hand in a basin of such water; for the lower limbs a swimming bath (*infra*)* is of great value. It is, however, essential not only to regulate carefully the therapeutic use of water, but to warn the patient against putting his hands or feet into very hot water or of exposing an affected part to cold and drafts.

The wider recognition of the importance of this local treatment of the paralyzed and anesthetic regions has been one of the most important lessons of the war, and it is the more to be insisted upon, as it should be commenced from the earliest moment by every medical officer.

With these accepted methods of assisting regeneration we may also refer to one or two others. The injection of thiosinamin is said to cause absorption of pseudoneuromata and thus relieve symptoms due to compression or to neuritis.[30] Ionization, radiotherapy, and diathermy have been found to give good results in painful lesions (Cestan,

* See page 530, on Injuries of the Spinal Cord.

Descomps, Grünspan, Babinski, etc., quoted by Tinel and Benisty), and with these may be adopted any of the measures used in other forms of neuralgia for the relief of pain.

4. The **orthopedic treatment** is little more than an extension of the above principles to the later stages of convalescence, and aims at providing support accompanied by such exercise as is possible (the use of supporting boots, hinged splints, elastic traction bands, graduated exercise, and the like), the regulated use of the affected part, and also the moral uplifting of the patient. Games which employ the fingers (draughts, halma, puzzles, etc.), apparatus to allow use of limbs while supporting only such joints as may not be left to themselves (elbow splints, knee splints, wrist and shoulder splints, boots, etc.), are all of value and may lead up to useful work. For extensive paralysis of the lower limb the swimming-bath is invaluable (p. 530.) Apparatus which causes regulated and increasing movements by means of a pendulum or fly-wheel are employed for stiffness of the larger joints, but in no way replace the value of intelligent efforts. The air of hospitalism should be avoided; patients should at the earliest moment engage in useful or at least interesting work.

5. **Plastic Operations.**—Apart from plastic operations in connection with nerve suture it is occasionally possible to obtain approximation of the cut ends by excising bone and thus *shortening the affected limb*. This will not often if ever be justifiable in the lower limb, on account of the danger of weakening it, and of the importance of maintaining an equal length. At the wrist it is seldom necessary owing to the great relaxation which can be obtained by strong flexion. It is more useful in the case of injuries of the upper arm, and especially in injuries of several nerves near the elbow-joint. A section may be removed from the shaft of the humerus and approximations previously impossible may then be effected. As the relative length of the humeri is of comparatively little importance and the approximation of nerve ends is essential the resections should be sufficiently free to accomplish their object fully.

In permanent paralysis **tendon transplantation,** or attaching the tendons of healthy muscles to those which have been lost, is valuable. Thus in paralysis of the musculospiral or posterior interosseous nerve the intact flexor carpi radialis may be attached to the distal ends of the tendons of the thumb and first finger, and the flexor carpi ulnaris brought round and fixed to the extensor tendons of the three inner fingers; the pronator teres has also been attached to the long and short radial extensors of the wrist. Similarly, in paralysis of the external popliteal nerve or its branches the tibialis posticus can be inserted into the tibialis anticus or the common extensor of the toes, while an intact tibialis anticus has been attached to the tendons of the paralyzed peroneals. In the leg the results are, however, less satisfactory than in the arm, as after injury to the external popliteal there is seldom enough muscle power remaining to yield a vicarious supply. For the ulnar and median nerves this type of operation is rarely indicated, as end-to-end suture

is more readily effected than in the case of the musculospiral and external popliteal. In paralysis of the anterior crural the biceps femoris may be inserted into the patella.

This method of vicarious repair has long been used by Robert Jones[29] and others in cases of infantile paralysis; for injuries of peripheral nerves it is adapted to cases in which suture operations have failed, to extensive defects of such nerves as the musculospiral and external popliteal in which the limb cannot be shortened to allow approximation of the cut ends, and to such cases as that of the posterior interosseous of the forearm in which the nerve breaks up into many small branches which cannot readily be identified. The transplanted muscles possess from the outset enough tone to counteract deformity and frequently become re-educated sufficiently to allow voluntary control over the joint involved. (See Vol. II, p. 517 *et seq.*)

Tendon fixation may also be used to prevent or overcome deformities, the distal ends of the tendons of hopelessly paralyzed muscles being drawn up, fixed to the bones above, and so constituting extra ligaments. Lange's method consists in similarly bracing up bones by means of artificial tendons (floss silk boiled in perchlorid of mercury, kept in an alcoholic solution of perchlorid, and soaked in parolein) which are passed through holes drilled in the bone; such a course, however, will seldom be required. On the other hand, *arthrodesis* at the shoulder or elbow may render valuable a hand which would otherwise be useless from the flail-like condition of these joints, a result not rarely met with in paralysis of the Erb-Duchenne type.

COMPRESSION OF NERVES

A large proportion of peripheral nerve paralyses following war wounds is caused by the pressure of a cicatrix or by strangulation from fibrous adhesions arising from the surrounding tissues, bone callus, traumatic aneurysm, bullet, or other foreign body. The severity of the alteration within the nerve varies, depending upon the extent and intensity of the compressing lesion (the pathology of which is described by Cadwalader in another chapter of this volume). Here operation will frequently be indicated to liberate the nerve; the degeneration of axis-cylinders in such cases is more often incomplete than complete and the nerve sheath is intact, therefore the prognosis is generally good after complete surgical removal of the cause; unfortunately, the clinical signs of severe compression cannot be differentiated from those produced by complete anatomic nerve section, but in milder cases compression paralysis is apt to be much less marked and incomplete.

The treatment after the expectant period has elapsed must be essentially operative to remove the compressing agent. It is rare to find nerve trunks in such a condition from compression alone as to demand resection, although Tinel claims that "a good resection is far better than a bad liberation," and advises resection in all doubtful cases.

IRRITATIVE LESIONS OF NERVES

Irritative lesions of nerves are, as a rule, associated with partial section, although they may also occur after complete division and after amputation. The essential cause is doubtless in most if not in all cases a septic infection of the nerve giving rise either to a local inflammation, as in painful "end bulbs," or to a spreading neuritis. The coexistence of such inflammatory changes with partial or complete section gives rise to very complicated symptoms which, however, prove capable of some classification. They differ widely from the syndromes of both interruption and compression.

The principal characters of the syndrome are as follows, it being assumed that section is incomplete: Paralysis is partial; simple muscular atrophy is slight; the reaction of degeneration is ill-defined and is often spoken of as "partial" R. D.; idiomuscular contraction is generally well marked; hypotonia is less prominent and may be replaced by spasm. Sensory symptoms are more obvious than are motor, and pain is severe. Of burning, pricking, or tearing character, it usually begins a few days after the injury, and it tends to increase steadily and to be aggravated by all movements, contacts, or changes of temperature. The skin is, as a rule, hypo-esthetic, but anesthesia is seldom complete, and all forms of stimuli react as pain. Trophic disturbances are marked. The skin may be dry and desquamating, but is more often covered with profuse perspiration, which may be fetid; the changes in nails and hair are more marked than in cases of simple interruption; the muscle bellies become infiltrated with fibrous tissue and then undergo cicatricial contraction, producing serious deformities, especially in the hand; joints and tendon sheaths are inflamed and tend to form adhesions; decalcification of bony tissue is often seen. Together with the pain and other local symptoms there is often much secondary mental disturbance and loss of morale.

As interruption is incomplete, paralysis and anesthesia tend to pass away gradually and pain subsides after a time. But the serious trophic changes persist and are very crippling. For many weeks or months the nerve is tender at the point of injury; formication below this point makes its appearance at a late date, and during recovery spreads down the nerve, so that it "gradually replaces the neuritic pain, driving it forward as it were" (Tinel).

Mild types of irritative lesions are described by Tinel and others as "the simple neuritic type" and the "attenuated neuritic" type. In the first, which may result from even a slight bruise, there is merely neuralgia with hyperesthesia to pin-prick and sensitiveness of the muscles, especially on extending the joints; paralysis is absent or is replaced by slight weakness and there are no trophic symptoms; the prospects of recovery are very good. In the "attenuated neuritic" type, on the other hand, there is a stronger tendency to fibrosis of the muscles and hence to contractures and deformities, especially of the hand and foot; pain and sensory symptoms are less marked, and the nerve lesion may even be overlooked while the muscles are becoming

much crippled. These two subvarieties of minor irritative lesion may perhaps best be contrasted by describing them respectively as the "neuralgic" and "myotrophic" forms of neuritis.

A far more serious variety described as "ascending neuritis" is, fortunately, a very rare result of wounds of the nerves. Due probably to septic infection running along the nerve trunk, it produces the symptoms of irritation, often with severe pain, and the disease gradually spreads up to the plexus, while symptoms may even involve the opposite limb. It naturally produces the most serious symptoms and, so far, no satisfactory treatment has been suggested.

An almost equally serious and a more common form of irritative lesion is that described by Weir-Mitchell as *causalgia*, and by Stopford[31] as *thermalgia*. This condition—most often met with in the median or sciatic* nerve or in the brachial plexus—was fully described by Weir Mitchell, Moorhouse, and Keen in the wounded of the American Civil War, but, owing to its rarity in civil life, it was almost lost sight of until its recent reappearance. Some days or even a week or more after the wound an intense burning pain commences in the palm or sole of the injured limb. Of paroxysmal character, this pain is aggravated by the slightest movement or contact and even by stimulation of distant parts (synesthesialgia) or mental shocks and surprises. In its intensity, its paroxysms, its tendency to be evoked by light rather than by firm touches, and its intractibility to all ordinary treatment, the pain closely resembles trigeminal neuralgia. With it are usually associated marked trophic changes in the skin, which, it is important to note, often extend well beyond the territory of the injured nerve; dryness of the skin is especially well defined and the patient himself constantly seeks relief by wetting it; local rise of temperature may simulate suppuration. After a long period the pain of causalgia tends gradually to diminish and disappear, but the condition is apt to leave much muscular fibrosis and contraction with osseous atrophy, marked local anemia, and even gangrene.

Paralysis of voluntary muscles is no part of the picture, although such may be present in the highly complicated lesions of the brachial plexus. Pathologically causalgia is found to be due to partial section associated with intraneural hemorrhage and sclerosis, which may or may not be septic, and its marked frequency in military surgery is doubtless due to the tendency of missiles to inflict incomplete lesions with much contusion. In several cases examined by Stopford[32] there was found extensive endarteritis in the affected area, and it is by no means improbable that this plays a considerable part in determining the symptoms and results.

In the **treatment of irritative lesions** it is essential to realize the nature of the pathologic condition which is producing the symptoms, and we find that these conditions fall into two great groups, viz., those in which the essential trouble is extraneural (cicatrices, foreign bodies,

* When the sciatic is affected the internal division always suffers with or without the external (Stopford).

fragments of bone, aneurysms) and those in which it is intraneural. The latter, which we may call generally neuritis, include the results of hemorrhage, certain neuromata, and especially spreading inflammation of the nerve sheaths of septic origin. Different conditions may, however, be closely associated, as when external pressure upon a nerve is followed by internal neuritis, and in any such doubtful case it will be wise to search for and remove a source of pressure at the earliest possible moment. Hence foreign bodies and bony fragments should be taken away without awaiting healing of the original wound, the nerve itself not being unnecessarily interfered with at this stage. Drainage should be thorough, but, naturally, no form of drain should be left in contact with a nerve trunk.

External irritation having been removed, attention will next be turned to the relief of pain. Apart from ordinary methods of treatment by drugs, galvanism will generally be found most soothing. The negative pole is placed on the affected nerve and the positive pole on the hand or foot, or in a basin of saline solution into which the limb is dipped, and a current of about 50 milliampères is then allowed to pass for some fifteen minutes (Grünspan), or with a current of, say, 3 to 5 milliampères the bath may be continued for several hours. The various baths already referred to in connection with orthopedic treatment may also be used in relief of pain, and radium is said to have given good results in obstinate cases.

In true causalgia such measures will rarely be effective, and even such radical treatment as the resection of the injured area of the nerve may fail to give relief, nor is posterior rhizotomy always effective. The character of the pain, the spread of trophic changes beyond the territory of the injured nerve, the local rise of temperature due to vascular dilatation, and the fact that causalgia is most common in the case of nerves with large accompanying arteries (median and sciatic) suggest that there is here an affection of the sympathetic fibers,[31] and on this basis Leriche[33] has advocated removal of the sheath of the main artery of the limb in order to divide such sympathetic fibers as may lie therein. Good results are claimed from this operation in cases of median causalgia. Its physiologic basis is, however, doubtful, as it has been shown that the nervi vasorum do not run as a continuous plexus in the sheath of the vessel, but join the latter throughout its course. On the other hand, Buzzard[34] and Sicard[35] have advocated injection of alcohol into the affected nerve above the lesion. The trunk having been exposed, a fine needle is thrust into its sheath about 3 or 4 cm. above the wound, and 1 or 2 c.c. of 60 per cent. alcohol injected so as to distend it for a distance of 3 or 4 cm. That pain can thus be relieved is unquestionable, but it is still too early to say whether it presents the same tendency to return after many months as does trigeminal neuralgia similarly treated. Sicard has, however, recorded cases of freedom from pain for nearly three years, and in view of the tendency of causalgia to ultimate recovery alcohol injection probably gives a sufficient period of relief. Joyce states that he has found the

method to fail where subsequent resection has succeeded, and he also records cases in which it has produced paralysis, but does not mention the alcoholic strength employed. Sicard admits that motor paralysis may ensue, but claims that this passes off in from six to ten months. Souttar and Twining prefer resection of painful cases if there be any paralysis, on the ground that alcohol injection probably so impairs the nerve as to make subsequent suture unreliable.

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CHAPTER XXI

MILITARY SURGERY OF JOINTS

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The experiences gained in the recent war resulted in striking changes in the treatment of wounds of joints caused by projectiles. During the early years of the war poor results usually followed these lesions by reason of an undervaluation of the resistance to infection which the synovial membrane of a joint offers, a failure to comprehend the proper operative procedures, and the universal employment of prolonged immobilization. But in the last eighteen months or two years methods of treatment were adopted in the Allied Armies which gave results far superior to any that preceded. We will describe these methods; unfortunately, space prevents more than passing notice of the steps by which they were developed.

Although attention must be focused upon the operative treatment as the most important factor, the preoperative management of the patient cannot be disregarded. As soon as possible after the receipt of the wound a first-aid dressing should be applied. Active hemorrhage, as a rule, can be controlled by a light pressure-bandage over the dressing. This failing, a tourniquet may be applied. It must be emphasized, however, that a tourniquet is a dangerous accessory. It should be applied close to the wound, and should be removed as soon as possible. It is essential in joint wounds that the part be immobilized before the patient is moved. In a large proportion of cases, especially when associated with fracture, traction also should be applied.

For *transportation* in the advanced area the following splints are advisable.* For fractures involving the knee-joint the Thomas leg splint and the hinged half-ring modification (Blake-Keller) are applicable. A litter bar attached to the stretcher supports the injured limb during transportation.

For slight injuries of the knee-joint without marked effusion, also for injuries to the ankle and tarsus, the Cabot posterior wire leg splint is advisable. This splint provides immobilization only.

For injuries of the hip-joint the Thomas traction leg splint or the long Liston splint should be used.

For injuries involving the shoulder and elbow the hinged modification of the Thomas arm splint is useful when fixation and traction are desirable. The advantage of the splint is that the injured limb may be brought to the side of the body for recumbent transportation, which

* Manual of Splints and Appliances for the Medical Department of the United States Army, 1917.

cannot be done with the ordinary Thomas arm splint. For the smaller joints, which need only immobilization, the ladder splint or the wooden coaptation splint may be used.

The wounded are received at a front hospital, for instance, a Mobile Hospital or an Evacuation Hospital, from about four hours to twenty-four hours or more after the receipt of injury. Their previous treatment, besides a first-aid dressing for the wound and a temporary splint for immobilization, has consisted in the administration of antitetanic serum and appropriate treatment for those presenting a condition of shock. The patients on arrival at the hospital present various degrees of shock, hemorrhage, laceration of soft parts, and associated lesions. The wound or wounds contain pathogenic micro-organisms and, in most cases, foreign bodies. The devitalized tissues provide an admirable medium for the growth of micro-organisms, which, however, lie dormant for a time, roughly from six to eight hours, after which they become active and infection progresses with variable rapidity and intensity.

Indications for Operation.—All wounds of joints by projectiles, except certain perforating (through-and-through) wounds by bullets, should be operated upon. Perforating bullet wounds are not operated upon if the wounds of entrance and exit are punctate and there is no evidence of displacement of fragments or hemorrhage. Punctate wounds are made by a bullet of high velocity with no explosive effect and no deflection during its course through the limb. In such cases the bullet cuts through clothing and tissues, carrying few organisms into the wound and producing little destruction of soft tissues or comminution of bone. Experience has demonstrated that under these conditions infection rarely occurs even when a fracture is present. Therefore these cases do not demand immediate operation. They should, however, be carefully watched, and distention of the joint should be treated in the manner described in the after-care of operated cases.

In all other cases operation should be performed as soon as possible after the receipt of the injury. Delay increases the danger of and from infection by reason of the bacterial types which are usually present and the characteristics of their growth and penetration in the tissues. But before operation certain preliminary precautions are essential. Thus:

A careful examination by the surgeon of the patient and his lesions is essential. The general examination should be sufficiently thorough to preclude the possibility of a serious associated lesion being overlooked. The degree of bone involvement and the presence and position of retained foreign bodies should be established by the *x*-ray. The surgeon should satisfy himself as to whether there is or is not a nerve lesion; this is especially important in the upper extremity. He must also examine for arterial lesions, especially in wounds of the lower extremity; the presence or absence of the anterior and posterior tibial pulse should be noted. Moreover, the time elapsed since the wound was received, the situation of the wound, the extent of injury to the soft parts, and the

general condition of the patient are factors which must be weighed before a plan of action can be decided upon.

Roentgenologic Examination.—The success of the operation depends largely upon the thoroughness of the roentgenologist's examination and the accuracy of his findings. His report should be made according to a definite system. The following routine has been found the most satisfactory:

Anatomic site and size of each foreign body in millimeters, depth in millimeters, position of the part, if it is not in the anatomic position; bone lesions. For instance, "Right knee, FB 10 x 15 mm., 50 mm. in depth, under the point marked on the skin, the limb being in 45 degrees outward rotation; comminuted fracture of internal condyle; no displacement."

The Preparation of the Patient.—The local preparation is usually done in the operating room on an extra table while the preceding operation is being completed. The wound being protected with gauze, the surrounding skin is shaved and scrubbed with soap and water. Application of chemicals may follow. The usual procedure is to cleanse with ether, following this with the application of tincture of iodin. It is important to prepare a wide field; even to encircle the limb. The part is draped with towels and sheets.

A general anesthetic should be employed save in exceptional cases. Nitrous oxid-oxygen, administered by an expert anesthetist, is the least harmful. It should be the anesthetic of choice for patients in a condition of shock. Ether, however, is employed in routine cases.

After careful consideration of the factors enumerated above the surgeon should proceed as far as possible in accordance with a definite plan. The choice between amputation and conservation of the limb should be made if possible before the operation is begun, so that the patient may be spared futile efforts to save the limb. Irreparable mutilation of the soft parts, excessive comminution of bone, wounds of the main vessels of the limb, especially in the lower extremity, irremediable injury to essential nerves, or advanced gas bacillus infection are the main features which call for the consideration of amputation. The condition of the patient is often the deciding factor. But the results of conservative treatment are sufficiently good to weigh in its favor in cases of doubt. Amputation is indicated in a relatively small percentage of cases.

Conservative operative treatment of recent wounds of joints has for its object, first, the prevention of infection; second, the preservation of function.

The important features are thorough débridement,* complete closure of the joint, and early movements.

* To débride (noun débridement), from the French verb *débrider*, means, strictly, incision and opening up of the wound; *épluchage* (verb éplucher) means the cutting or paring away of contused and contaminated tissues. The term "débridement" is now almost universally used in English to signify not only the opening of the wound by incision but also the excision of the damaged tissues as now practised in war surgery.

The adoption of these principles in the recent war followed three well-defined stages:

1. Débridement; drainage; irrigation with antiseptic solutions; immobilization.

2. Débridement; Carrel-Dakin treatment of the joint; immobilization.

3. Débridement; lavage of the joint with Dakin's solution or ether; joint suture, with drainage of the joint for about twenty-four hours; immobilization; passive movements and massage in eight to ten days.

During the development of these methods the results improved progressively, but were not satisfactory, as was demonstrated by Depage, at La Panne, Belgium, where these procedures were conscientiously carried out and the results analyzed. It was recognized early in the war that the main features which are of importance in the treatment of battle casualties of other types, particularly early operation and thorough débridement, are likewise indicated in the treatment of wounds of the large joints. But, whereas in other types of wounds it is often advisable to leave the wound unsutured and to supplement the operative treatment by chemical sterilization before proceding to a final closure, it was found that an unsutured joint in general did not progress satisfactorily. In such cases postoperative chemical sterilization could not be depended upon, and the introduction into the joint of drains, such as rubber tubes, was found to result disastrously, in that they often introduced infection and caused pressure necrosis, thus diminishing the resistance of the synovial membrane and articular cartilage to infection. Moreover, they failed to accomplish their purpose, that is, to drain the joint. Immediate closure of the joint by suture was found to be essential to success. Therefore the surgeon must rely upon the primary operation for the prevention of intra-articular infection, which is the immediate aim of conservative treatment. The important factor being the débridement of tissues, the principles of this, as applied to wounds of the soft parts, bones, and cartilage, must be fully understood.

Technic.—The details of a conservative operation may be summarized as follows: Complete débridement of the tract of the projectile through the soft parts and bone; removal of foreign bodies; thorough irrigation of the joint; absolute closure of the joint by suture; primary or delayed closure of the superficial parts according to the rules laid down for primary suture of the soft parts alone; finally, early active motion.

The incision or incisions must be placed so as to permit not only thorough débridement of the soft parts but also free access to the foreign body and involved bone. Though no rules can be formulated, longitudinal incisions are to be preferred when practicable. However, the position of the wound or wounds and that of the foreign body are, in general, the determining factors. The primary incision includes the wound of entrance and is often supplemented by a second incision. In a perforating wound the second incision usually includes the wound of exit;

in a penetrating wound it is placed in such position as to expose a retained foreign body which otherwise would be inaccessible. The incisions must be of sufficient length to give adequate exposure (Fig. 194).

Through these incisions débridement of the soft parts (Fig. 195) proceeds as in operations elsewhere. The technic is practically the

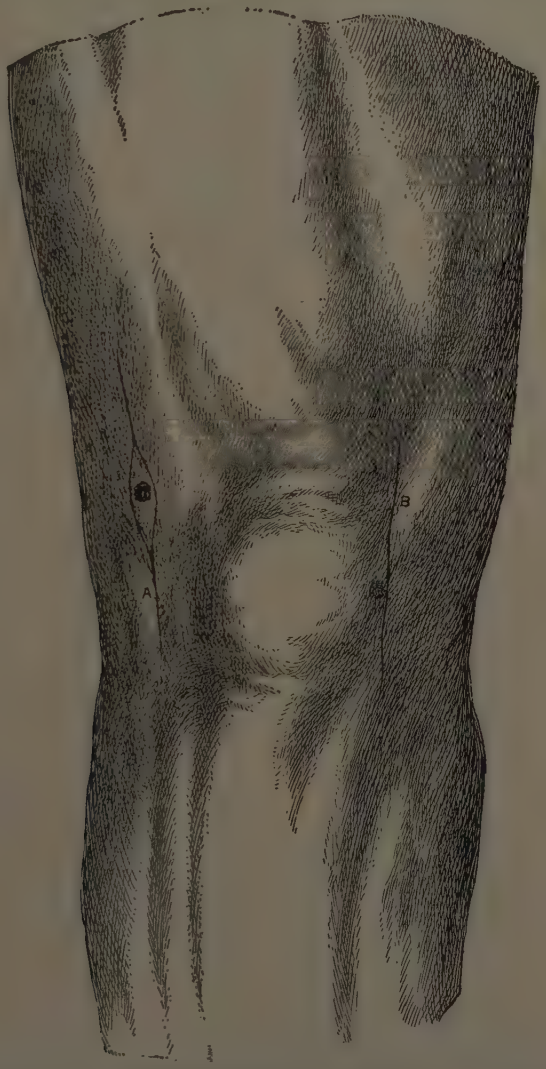

FIG. 194.—A, INCISION FOR DÉBRIDEMENT OF WOUND OF ENTRANCE. B, INCISION TO EXPOSE RETAINED FOREIGN BODY. (See Fig. 195.)

same as for wounds of the soft parts alone, but the refinements of technic in respect to asepsis and adequate exposure must be fully observed, and traumatization of the synovial membrane should be reduced to a minimum.

It is sometimes difficult to identify the opening in the capsule or even to determine whether the joint has been penetrated. This difficulty is met most often in the case of small perforating and penetrating wounds with little or no bone involvement in which a fragment of shell has either perforated the limb, traversing the joint in

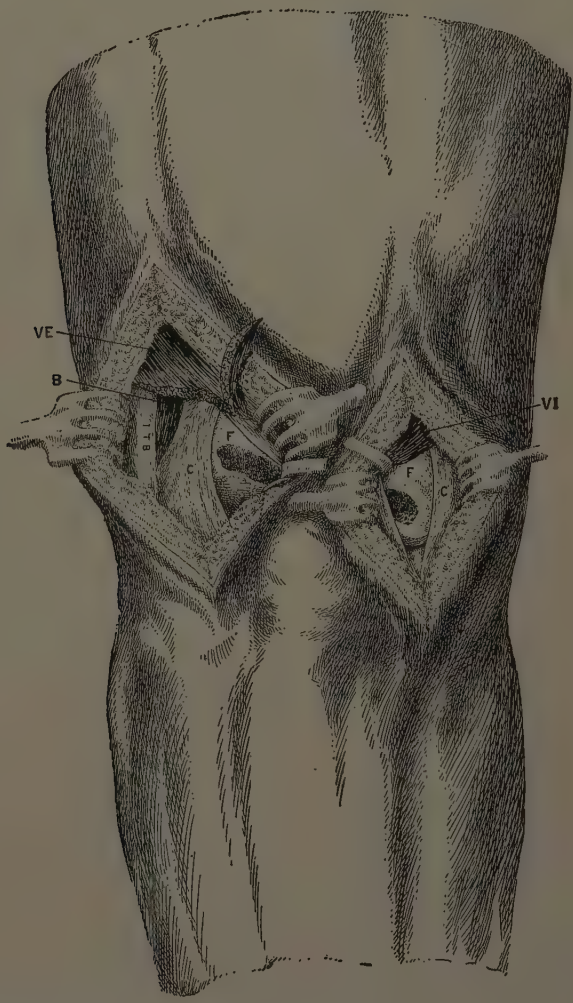

FIG. 195.—OUTER SIDE, AFTER DÉBRIDEMENT OF WOUND AND OPENING OF CAPSULE.
Dotted lines indicate extent to which capsule has been opened. Inner side: arthrotomy to reach foreign body in inner condyle. F, Femur internal and external condyle with gutter wound débrided; C, Capsule; VE, Vastus externus; ITB, Iliotibial band; VI, Vastus internus; B, Biceps femoris.

its course, or has penetrated the joint and lodged in it or in adjacent tissues. But, after the capsule has been exposed in the débridement, the orifice into the joint must be demonstrated before the joint is opened. Great care should be exercised to avoid opening a joint that

is uninvolved, and, similarly, not to neglect proper operative measures in a joint that is involved.

The capsule and synovial membrane should be opened by a liberal incision with thorough elliptic excision of contused or contaminated tissue, conserving, however, all tissues that can be left safely. Foreign bodies must be removed. The subsequent steps depend upon the presence or absence of a bone lesion. If none exist, the joint is irrigated and closed; if a bone lesion is present, it must be appropriately treated before closure of the joint.

In all cases contaminated bone surfaces must be cleansed as thoroughly as possible; that is, treated on the principle of removal of contaminated tissue. This is done with gouge, chisel, or curet, with the sacrifice of as little bone as possible.

An intra-articular wound of the bone or cartilage, such as a gutter, depression, or canal without complete fracture, constitutes the simplest type of lesion. The bone wound should be cleansed as above described.

When there is an injury to an articular surface consisting in a limited and incomplete separation of a layer of cartilage with a thin layer of underlying bone, it is advisable to remove the partly separated and poorly nourished cartilage and with chisel, gouge, or curet to cleanse the surface from which it has been detached.

Where a fracture line has resulted in partial detachment of a large fragment of bone with its articular surface, but the fragment retains good contact with the soft parts, it is left after the tract has been followed and contaminated surfaces have been cleansed as thoroughly as possible. But under such conditions it is important that the fractured surfaces be left in close contact. An intervening space interferes materially with union, as Cotton emphasized years ago.

If an attached fragment is to be removed, this should be done if possible by the subperiosteal method of Ollier, using the Lériche modification of the sharp Ollier elevator. By this method a re-formation of the bone is more probable.

In extensive involvement of the articular surfaces an effort should be made to save the joint, provided the conservable articular surfaces and soft parts are sufficient to warrant a reasonable hope of securing a useful joint. In this connection it must be borne in mind that stability is essential in the knee and ankle, that is, in the weight-bearing joints.

When there is such loss of the articular surfaces as to preclude obtaining a useful joint, resection should be elected. A classical resection should be done when stability and rigidity are desired, as in the knee, otherwise an atypical resection may be made.

The final steps of the operation in all cases are as follows: Complete hemostasis should be secured. The joint is then thoroughly washed with salt solution to remove blood-clots, bone fragments, and débris. Some operators recommend that this be followed by lavage with ether under sufficient pressure to distend the joint. However, this use of ether is empiric; it is questionable whether it exerts any beneficial influence. The synovial membrane and capsule are closed with fine

chromic gut which should be, as far as possible, extra-articular. When feasible, these two layers should be sutured independently. Complete closure of the joint without drainage is the invariable rule.

When there is such destruction of the soft parts that the edges of the capsule cannot be approximated, if an attempt is to be made to save the joint, the defect in the capsule should be completely closed with muscle or fascia, using a pedunculated flap if necessary. In a few cases in which this was impossible we have seen a partial closure made and the wound treated by the Carrel method, the aim being to close the joint subsequently by a plastic operation. However, we have not seen this method successfully carried out without infection.

The soft parts overlying the capsule may be closed or left open for subsequent suture. If the ideal conditions, that is, early and thorough débridement, have been approximated and the case can be watched for some days, primary suture may be made. Otherwise, the wound is left open and sutured subsequently. In active periods, as an offensive, with a large number of wounded, the exigencies of the service demand haste in the primary operation, and the case must be evacuated and pass from the operator's control soon after the operation. Under these conditions primary suture of the superficial tissues should not be considered. It may be employed only in quiet periods and in hospitals where patients can be watched. In this connection it must be urged that cases of wounds of the large joints, *e. g.*, knee, should be included in the non-transportable class after operation, when conditions warrant their retention.

The advantages of primary suture are obvious; the disadvantages consist chiefly in the danger of closing within a wound, especially within a wound imperfectly débrided, pathogenic micro-organisms. A resulting gas bacillus infection or virulent pyogenic infection in a few cases will counterbalance many successful closures. Moreover, primary suture increases the danger of joint infection by inward extension of a superficial infection. The danger, however, is lessened if interrupted silkworm sutures, placed at rather long intervals, are employed for the approximation of skin and subcutaneous tissues.

If the soft parts are left open, vaselin gauze or other bland non-adhering gauze is placed along the edges of the wound so as to cover the skin edges and subcutaneous tissues. This prevents the dressing adhering and lessens hemorrhage and pain on its removal. Gauze soaked in Dakin's solution is placed very loosely in the wound. It should be so adjusted as not to cause retention of secretions.

In cases in which there is an extra-articular lesion of bone in conjunction with a joint lesion, the joint is treated and closed as described; the extra-articular bone lesion is appropriately treated and the wound of the soft parts is left open. Every effort should be made to close such a wound by delayed primary suture because prolonged exposure will often result in infection (frequently with streptococcus), and infection will secondarily involve the joint.

Postoperative Care.—The ultimate aim of treatment is to restore

the individual to full activity with complete restoration of function in as short a time as possible.

Early Active Mobilization.—It must be emphasized that early re-establishment of the function of the part is dependent upon early active mobilization. Before the war immobilization for a considerable period after operations upon joints was the usual practice. Complete loss of function, limitation of function, or delay in return of function frequently resulted.

Having in view the early and complete re-establishment of function, Willems, of Hoojstade, Belgium, urged that postoperative immobilization should not be employed, and demonstrated the correctness of his claims by a series of brilliant results. Other surgeons were slow to accept his method to the extent of adopting immediate mobilization with the elimination of all splinting. But various operators have practised short periods of immobilization, and all have of late inaugurated movements at an earlier date than was their former practice. Moreover, as the beneficial results and relative freedom from complications have become evident, they have gradually approached and even followed Willems' plan. An example of the conservatism which has prevailed may be illuminating. Thus, in 1917, Cook advised "that when the object of treatment is mobility, and the asepticity of a case has been provisionally established—*i. e.*, after the temperature has been normal for about a week—light movements are applied. Further treatment in this direction is regulated by absence of reaction and comparative freedom from pain."

In our own experience we were taught the Willems method at La Panne in the winter of 1917–18. The method, however, was not at that time generally accepted, so in our early work with the A. E. F. at Evacuation Hospital No. 1 we were somewhat conservative in its application. In general, we employed a splint for a brief period, but enforced early movements whenever practicable. As a means of recording the range of motion we found it convenient to use a diagram (Figs. 196, 197). The date is entered on the arc opposite the degree of motion.

Dowden states without reserve that, owing to the practice of immobilizing joint lesions, thousands of British soldiers have been rendered cripples for life. In this respect views as to the treatment of joint injuries have undergone a radical change as the result of the experiences on an unprecedented scale in the recent war.

It may properly be urged that after operations for recent joint wounds immediate mobilization should be employed in all cases in which a fracture does not contraindicate, or the character of the wound of the soft parts is not such as to interfere with repair of the wound. The patient should be encouraged and directed to move the joint as soon as the operator feels that this can be done without interfering with tissue repair. For instance, following a transverse wound with removal or suture of the patella or after suture of an extensive wound of the thigh, a period of immobilization must be enforced. *In the treatment of*

wounds associated with fracture mobilization of the joint is not indicated if it is likely to interfere with alinement or union or promote excessive

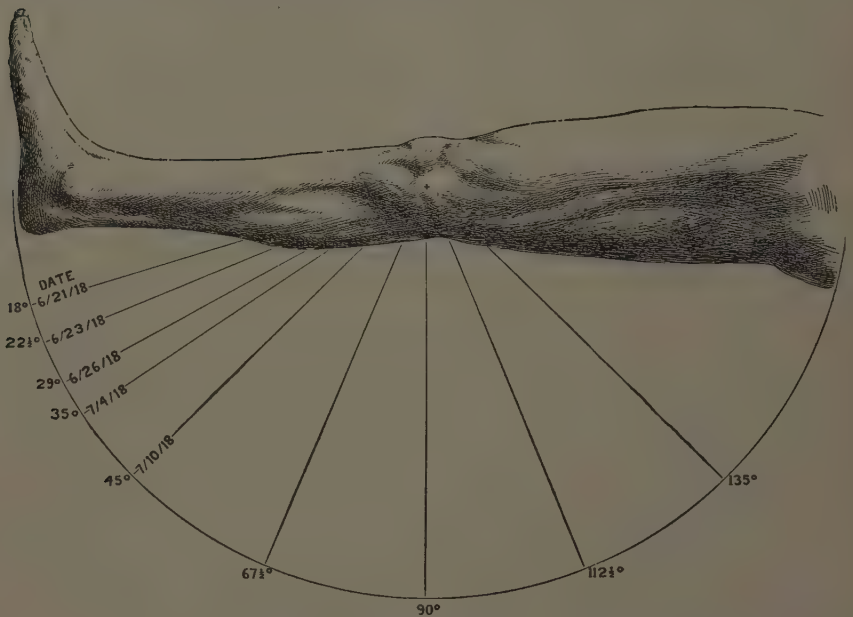

Fig. 196.—A Convenient Method of Recording the Range of Motion.

callus formation. But Willems claims that constant mobility prevents the development of intra-articular callus and, therefore, is advan-

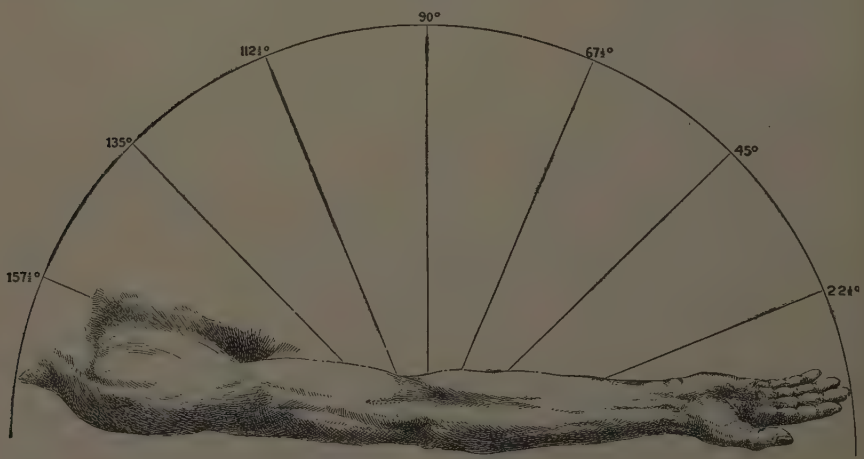

Fig. 197.—The Same Method of Recording Motion in Elbow.

tageous rather than harmful. On the other hand, in the type of wound with little involvement of bone and soft parts, a splint should not be applied. The patient should flex and extend the knee as soon as he

has recovered from the anesthesia. The movements must be active, not passive; they should be as extensive and frequent as feasible. Little pain is experienced if the movements are begun early. The supervision of a nurse for the direction and encouragement of the patient is essential. Delrez recommends that patients with little or no bone injury should be out of bed soon after the operation, even as early as the second day. In wounds of the lower extremity they are encouraged to walk, gradually increasing the amount from day to day. Crutches and cane are used at first, but are soon discarded. In the case of joints of the upper extremity patients are directed to scrub and sweep, gradually increasing the period of work. In cases with a bone lesion the patient is kept in bed for a longer period, the time being roughly proportionate to the degree of bone injury. In cases associated with fracture they are encouraged to get out of bed and use the limb as soon as this can be done without endangering alinement and union. Early use of the joint is essential for early restoration of function.

Treatment of the Wound.—A wound which has been closed by primary suture should be examined within twenty-four hours; moreover, the general condition of the patient should be carefully watched. These precautions cannot be too strongly urged. If they are followed there is not much danger of fatal infection; if they are neglected, avoidable fatalities will occur.

Obviously, one of the conditions of early restoration of function is the repair of the wound. Therefore, when the soft parts have been left open, the wound should be closed as soon as possible by delayed primary or secondary suture. The distinction between delayed primary suture (Duval) and secondary suture is one of tissue repair rather than of time. Delayed primary suture is one in which the edges can be approximated and will unite without excision of tissue; this is, in general, about one week. Secondary suture is one in which the epidermis has grown inward and must be excised for proper union to take place. In late secondary sutures dense granulation tissue must also be excised from the surface of the wound and the skin must be mobilized. The determination as to when a wound may be sutured depends upon bacteriologic findings and clinical observation. It must be emphasized that the co-operation of a bacteriologist is indispensable in making a decision as to the indications for delayed primary and secondary sutures. In the consideration as to whether a wound is suturable or not, reliance must be placed chiefly upon cultures, the important feature being the determination of the presence or absence of hemolytic cocci. For this a routine blood-agar examination is essential.

Bacterial counts are far from exact, yet they give an indication as to the degree of bacterial contamination of a wound, especially the progress from day to day.

Eighteen to twenty-four hours after the original operation of débridement or excision of tissues the wound is dressed and a culture and a smear are made. If no organisms are found, suture is indicated. If hemolytic cocci are present, suture is not considered. In the absence

of hemolytic cocci, if the wound is clinically suturable, the presence of a few anaërobes or other organisms (approximately 1 in 2 fields) does not contraindicate suture. A considerable number of organisms of any kind indicates caution. Suture in that event should be delayed and a culture and a smear repeated at the following dressing.

When a wound is left open for a considerable time cultures and smears are made at regular intervals. The reports contain the approximate number of organisms per field and the varieties of organisms. When the organisms in two successive counts are few, that is, approximately 1 in 2 fields, and a culture shows an absence of hemolytic cocci, the wound is considered susceptible of secondary suture, except when the wound has contained hemolytic cocci at any time. In that case careful cultures are made from granulation tissue and from the discharge from all parts of the wound; and absence of hemolytic cocci should be established by two successive negative cultures before suture is made. It has been observed that streptococci are prone to lie dormant in small numbers, and to flare up and cause virulent infection after closure of the wound.

Delayed primary suture is usually made in from two to six days after the primary operation. The advantages are the practical elimination of gas bacillus infection and marked lessening of the danger of pyogenic infection. The disadvantages are the possibility of postoperative contamination of the open wound, the subjection of the patient to a second operation, and some interference with the institution of early movements. However, these disadvantages do not equalize the risk incurred by primary suture in cases which cannot be carefully watched.

All *dressings* of wounds after the primary operation should be made according to the Carrel-Dakin technic. The introduction of tubes to permit frequent chemical disinfection with Dakin's solution is indicated only in cases which are infected or which are evidently destined to be left open for a considerable time, that is, a week or more.

The *ante-operative preparation* of the wound for delayed primary or secondary suture consists in painting the skin with tincture of iodin after thorough cleansing, as in the routine dressing. Some operators also paint the wound surfaces.

Postoperative Infection.—Superficial infection may require the removal of only a few stitches; more extensive infection of the superficial tissues requires reopening of the entire wound to the capsule. The wound should then be Carrelled and may be suturable subsequently.

If the joint becomes distended, and infection is suspected, it should be aspirated immediately and a culture made. We have seen turbid fluid containing diplococci aspirated from a distended joint on the third day after operation and uneventful recovery follow. We have also seen much turbid fluid evacuated from between the sutures in the capsule on the second and again on the fourth day by pressure on the subcrural bursa. In this case the joint was markedly distended until

the fourth day. Possibly as a result of the distention there was no limitation of motion at any time. This patient quickly regained full motion and was back at the front in six weeks with perfect function.

If the patient's condition, the local examination, the character or culture of the aspirated fluid indicate pyogenic infection, one or more incisions should be made at once. But if the original incision is so placed as to allow satisfactory drainage it should be reopened and the

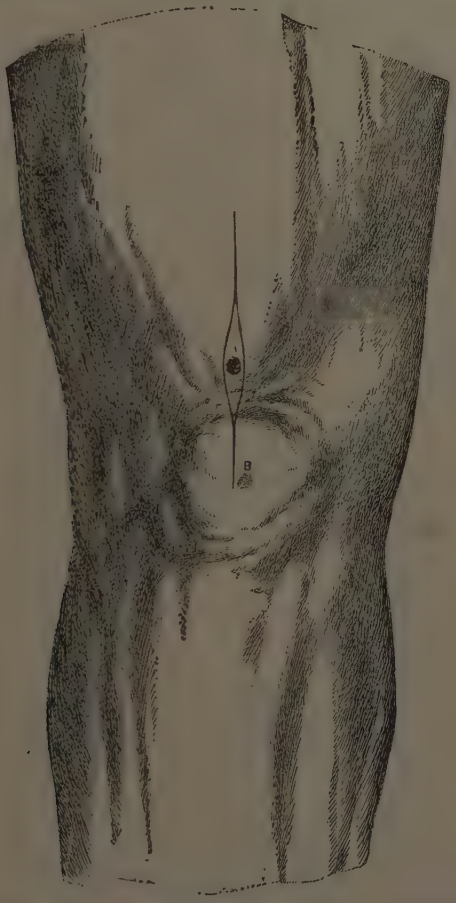

FIG. 198.—A, WOUND OF ENTRANCE. INCISION FOR DEBRIDEMENT. (See Fig. 199.) B, SITUATION OF FOREIGN BODY.

treatment for suppurative arthritis begun. Willems' method of drainage by active movements is here recommended. The important feature is to begin treatment early. No drains should be used. Splints are dispensed with or arranged for support without joint fixation. Free mobility every two hours should be enforced by *active movements* so as to evacuate the joint. Early non-virulent infections with little or no bone involvement usually do well. In severe or long-standing infec-

tions, especially with bone involvement, the treatment has not proved as satisfactory. The method will be described in detail in a later paragraph.

In two of my own cases where purulent intra-articular infection occurred and the joint was reopened, Carrel treatment was carried out for a few days and secondary suture of the joint was made successfully in eight days. The Carrel treatment is most appropriate in wide

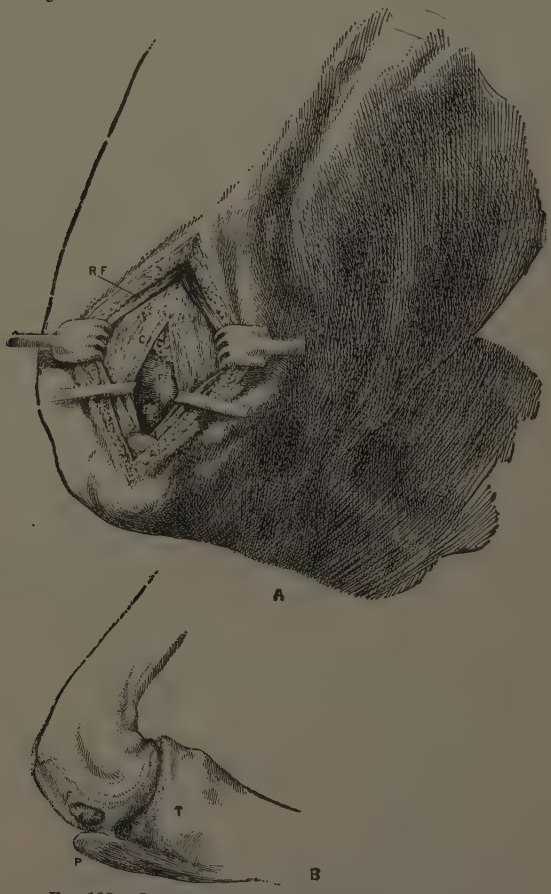

Fig. 199.—Incision in Capsule After Debridement.
Foreign body exposed by acute flexion of knee. (A). RF, Rectus femoris; F, Femur, articular surface; C, Capsule. (B). F, Femur, articular surface; T, Tibia; P, Patella.

open joints for a short period, and where the joint is opened soon after the infection has begun. Hughes and Banks have obtained admirable results by its use, especially in the elbow and shoulder, and have been able to sterilize the wounds and perform secondary suture in a large proportion of cases.

Knee-joint.—Certain details which bear upon individual joints, especially the knee, must be emphasized. For the initial operation, lateral incisions are to be preferred; but, as has been said, the situation

of the wound or wounds and the position of the foreign body must, as a rule, be the determining factors. Occasionally the incision may be curved or even transverse, but division of the patellar tendon should rarely be made and then only when full exposure of the joint is essential, as when a foreign body lies in the region of the crucial ligaments. When the wound of entrance is above the patella the joint may be explored to a considerable extent through the wound of débridement. In one of my cases a foreign body embedded low in the articular surface of the femur was brought into view above the patella by acute flexion of the knee. Removal of the foreign body and treatment of the bone injury were effected through this incision (Figs. 198, 199).

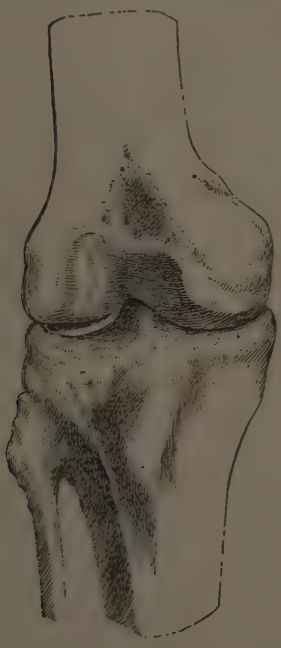

FIG. 200.—PARTIALLY DETACHED ARTICULAR CARTILAGE SHOULD BE REMOVED.

FIG. 201.—ARTICULAR CARTILAGE WITH CONSIDERABLE BONE, THE WHOLE ATTACHED TO SOFT PARTS, SHOULD BE LEFT.

The illustrations show the procedures usually followed for the various types of bone injuries: (1) A small partially detached piece of articular cartilage should be removed (Fig. 200); (2) articular cartilage with considerable bone, the whole attached to soft parts, should be left (Fig. 201); (3) extensive comminution of a condyle which necessitates its removal demands resection (Fig. 202). Removal of one condyle will result in so much lateral mobility as to necessitate later resection. In the decision between primary resection and conservation of an imperfect joint it must be borne in mind that stability is essential in the knee. (4) Where great disorganization of the articular surfaces exists immediate resection is indicated (Fig. 203). Tuffier affirms that this method of treatment forms one of the greatest advances made in

the surgery of the joints, and has caused a large diminution in the number of amputations of the thigh. Lériche advises that the tibia be nailed to the femur to prevent dislocation after resection. For this purpose Blake recommends two spikes, converging from each side of the tibia upward and inward into the femur. They are passed through the skin and the heads are left projecting. They are removed when union has taken place. According to Tuffier's observations 8 per cent. of primary resections of the knee resulted in amputation or death.

When the bone lesion is so extensive that resection would be necessary through the narrow shaft above the condyles, amputation is in general preferable (Fig. 204).

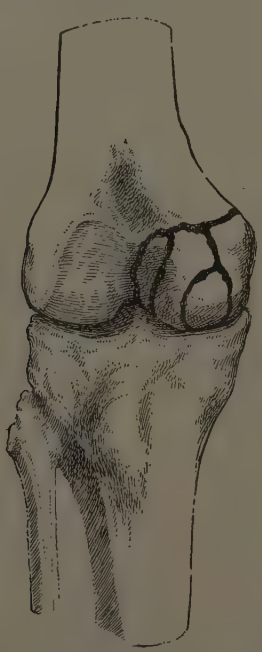

Fig. 202.—Extensive Comminution of Condyle Which Necessitates its Removal, Demands Resection.

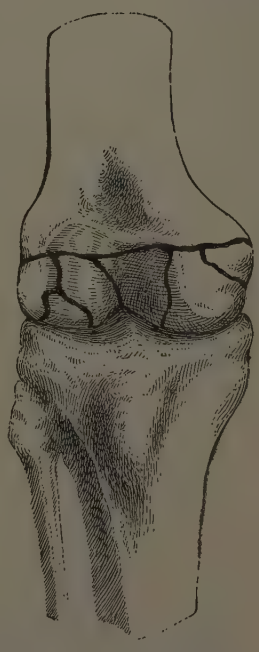

Fig. 203.—Such Comminution of Articular Surface as to Preclude Conservative Operation. Resection Indicated.

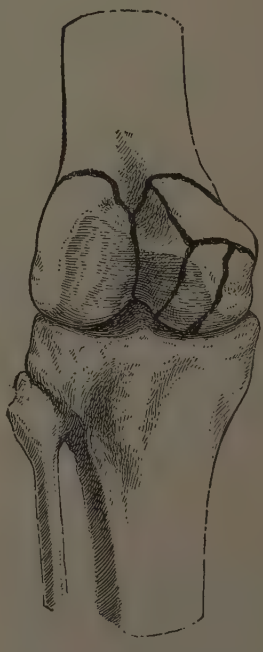

Fig. 204.—T Fracture. Resection or Amputation Necessary. Amputation Preferable to High Resection Through Narrow Shaft.

Compound fractures of the patella should be treated by removal of completely separated fragments and preservation of large attached fragments which should be approximated if possible by suture. Complete removal of the patella should be avoided, since the functional result is poor. However, when the patella must be removed a flap from the quadriceps tendon should be attached to the patellar tendon, as advised by Murphy.

Much difficulty may be experienced when excision of a portion of the head of the tibia has been necessary. The defect in the capsule is difficult to close. When the loss of articular surface is slight (Fig. 205)

it may be possible to supplement the deficiency in the capsule by turning a flap of fascia from an adjoining part and suturing it in place so as to complete the closure. If the loss of articular surface is considerable (Fig. 206), resection is usually necessary.

In compound fractures of the tibia in which the joint is not directly involved, but with one or more lines of fracture extending into the joint, intra-articular infection frequently develops. If hemarthrosis is marked we believe that arthrotomy, irrigation, and closure is in general indicated, in addition to the operative treatment of the wound and the fracture. Every effort should be made to convert the compound into a simple fracture at an early date by suture under bacteriologic control.

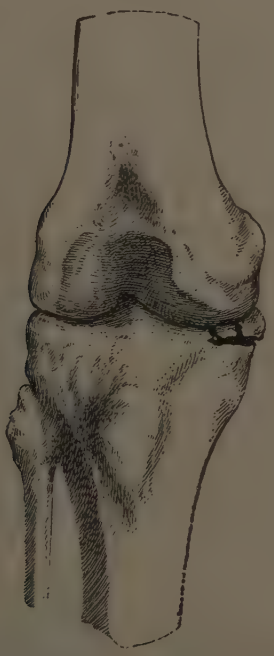

FIG. 205.—IF LOSS OF ARTICULAR SURFACE OF TIBIA IS SLIGHT IT MAY BE POSSIBLE TO SUPPLEMENT THE DEFICIENCY IN THE CAPSULE BY A FLAP OF FASCIA.

FIG. 206.—IF THE LOSS OF ARTICULAR SURFACE OF TIBIA IS CONSIDERABLE RESECTION IS USUALLY INDICATED.

In the cases which we observed in which an open knee-joint was associated with a wound of the popliteal or femoral artery, amputation ultimately became necessary except in two instances. One of these was an open knee-joint without bone involvement complicated by a wound of the popliteal artery. Arthrotomy and ligation of the popliteal artery (Jopson) were followed by a good functional result. The other was a case operated upon by Delrez. It was a penetrating wound of the popliteal space by a bullet, with division of popliteal artery and vein. The bullet was extracted under the method of Hirtz by trepanization of the condyle. Both vessles were doubly ligated. Mobiliza-

tion was begun four days later. There was almost complete restoration of function in six weeks.

An analysis of a series of cases of wounds of the knee-joint which were operated upon and followed by Jopson and Pool affords approximately the average figures for this type of wound:—

Total number of cases		34
Average time elapsing between receipt of wound and the operation (excluding one case of three days' duration)		11 hours
Shortest interval		3½ "
Longest interval		26 "
Type of missile	High explosive shell fragments	25
	Pistol	5
	Rifle or machine gun	4
Penetrating wounds	High explosive	23
	Pistol or rifle	2–25
Perforating wounds	High explosive	2
	Pistol or rifle	7–9
Wounds with bone involvement	Femur	12
	Femur and tibia	3
	Femur and patella	6
	Tibia	3
	Patella	4–28
Wounds without bone involvement		6
Complications	Multiple wounds	10
	Wound of main blood-vessels	3
	Femoral artery	1
	Popliteal artery	1
	Popliteal artery and vein	1
	Contusion of peroneal nerve	2
	Shock or hemorrhage, or both	4
	Gas gangrene (pre-operative)	2

In all except 2 cases the joint was sutured primarily. In one case primary amputation was necessary, and in another an attempt was made to save a badly shattered limb, in which the wound of the knee-joint was of secondary importance. This case came to amputation, but not for joint infection.

Primary amputation	1
Primary suture of joint	32
Primary closure of superficial wound	21
Delayed primary closure of superficial wound	4
Secondary suture of superficial wound	4
Evacuated before suture of superficial wound	2
Amputation for vascular gangrene before skin wound was sutured	1
Amputation for gangrene of foot in case in which joint and soft parts were not closed. Gangrene resulted from gaiter with traction for two days prior to admission (French soldier)	1

Total number of infections during stay in hospital	8
Infection of joint and soft parts	3
Infection of soft parts alone, severe, requiring reopening, Carrel and secondary suture	1
Infection limited and superficial, requiring the removal of only one or two sutures, not interfering with primary wound healing	4
Evacuated within twenty-four hours (this case was amputated at the Base, details are lacking)	1

While in 3 cases there occurred joint infection, in but 1 did this result in ankylosis. In the others the infection was controlled by

prompt reopening and Carrel treatment for several days. In both of these the joint and soft parts were sutured successfully after sterilization.

Secondary amputations. In 2 cases this was required before evacuation. In neither was it done for infection. In one it was for gangrene following an associated wound of the popliteal artery and vein, and in the second for gangrene of the foot, the result of prolonged pressure by the anklet used in connection with the Thomas splint, which had been in place for two days before admission. In another case, evacuated twenty-four hours after operation, the record shows the limb was amputated later at a Base.

End-results.—The average length of stay in the hospital was twenty-six days.

Deaths. Total number	2
Cause:	
1. Multiple wounds, gas gangrene, retroperitoneal infection.	
2. Multiple wounds, shock, gas gangrene.	
Amputations, primary	1
Amputations, secondary	2
Good functional result apparently assured at time of evacuation or from subsequent information. (Little or no limitation of joint movement, and a stable weight-bearing limb)	15
Fair result (partial limitation of motion after several months; good weight-bearing limb)	4
Poor result from standpoint of function (one complete ankylosis the result of infection; one secondary resection for weak joint)	2
Result as to function undetermined	7
One case evacuated within twenty-four hours, amputation at Base	1–34

A review of the above results has confirmed us in the opinion that a conservative policy in dealing with wounds of the knee-joint caused by projectiles is strongly indicated. It has shown that infection can be avoided in the great majority of cases; that even when intra-articular infection develops, function can sometimes be preserved, or if lost, that amputation is not inevitable; finally, that early active motion of the joint offers the best chance for an early and complete restoration of function.

Mouchet and Pamart reported the late results one year after early operations on 54 soldiers who had sustained wounds of the knee by projectiles, 49 being high-explosive shell fragments.

There were in 39 per cent. good results; 25 per cent. fair results; 35 per cent. bad results.

They found that the greatest functional deficiency occurred in cases of arthrotomy for wounds with bony lesions.

The worst results followed U-shaped arthrotomy.

Shoulder.—When resection is necessary for extensive comminution of the head of the humerus the subperiosteal method is strongly recommended by Lériche, who urges that great care be taken to preserve the continuity of the capsule and periosteum. He advises that the end of the humerus be immobilized for a time in the glenoid cavity and that movements be undertaken very gradually in order to avoid a flail joint. Conservation of bone is important. The extensive resections which were done during the second year of the war resulted in almost useless flail limbs.

Elbow.—In the elbow the conservation of bone is an object to be especially aimed at, therefore classical resections are less often advisable than in the knee. The head of the radius and the capitellum can be sacrificed without material loss of function, especially if active motion is begun early. When the internal condyle must be removed function is less perfect and lateral mobility is to be expected, yet the result may be fairly satisfactory. In more extensive lesions, especially when there is such extensive comminution of the articular surfaces that resection is necessary, the choice must often be made between a movable flail joint and ankylosis in a useful position.

If resection is performed by the subperiosteal method, which permits regeneration of bone, even extensive resection of the lower extremity of the humerus may be followed by favorable results. Le Fur believes that the bad results following this method are referable more to the destruction of the muscles and periarticular tendons than to the loss of bone. Lériche urges subperiosteal resection when the mechanism of the joint is seriously disturbed; that is, when the trochlea or the articular surface of the ulna are badly involved. He states that callus forms rapidly, that anatomic and functional restitution are gradually brought about, and that in many cases within a year after complete resection there is perfect pronation, supination, and flexion, with marked solidity. He closes the wound by delayed primary suture under bacteriologic check and does not employ the Carrel treatment; the arm is put up in acute flexion and full supination; very limited and infrequent active movements are begun in eight to ten days. He urges rigidity, and states that it is a flail joint and not ankylosis that is to be feared.

Unfortunately, under the conditions which prevail in the hospitals of the forward area subperiosteal resections can rarely be performed, nor can the intensive care which is necessary in the after-treatment be given the individual case.

Ankle.—In wounds of the ankle with considerable involvement of bone astragalectomy is usually indicated, followed by complete closure of the joint. As Chutro has emphasized, it is important to displace the foot backward after astragalectomy in order to provide a fulcrum of sufficient length, and to give proper weight-bearing lines. The ankle is one of the most troublesome joints to treat in the presence of infection. Suppuration often extends not only to the tarsal joints but also along the tendons of the foot, and amputation not infrequently results. Therefore a successful initial operation is especially important.

Wounds of Joints Produced by Sharp Instruments.—These should be treated on the principles outlined for wounds caused by projectiles. The soft parts should be thoroughly débrided; the joint widely opened, a wound of the bone or cartilage cleansed with chisel or curet, the joint irrigated, and the synovial membrane and capsule closed. The soft parts may be sutured or left open, according to the rules already laid down.

LATE COMPLICATIONS OF WOUNDS OF JOINTS CAUSED BY PROJECTILES

In general, wounds of joints which have been properly treated progress satisfactorily if infection does not occur, and a large proportion of the patients regain full function in a relatively short time. On the other hand, the occurrence of infection seriously affects the outcome; not only is the mortality greatly increased, but even in the more favorable cases re-establishment of function is often prevented by partial or complete ankylosis. These two complications, infection and ankylosis, must be discussed in some detail.

Suppurative arthritis constitutes the most serious sequel to wounds of joints. As an early complication it has been considered under the postoperative treatment of recent wounds. Attention must now be directed mainly to the treatment of the later and persistent phases of joint suppuration which constitute one of the most difficult and discouraging problems of military surgery. A large number of these cases were treated in every Base Hospital of the A. E. F. The most important factors which led to the development of chronic suppuration were ill-advised conservative measures rather than early operative treatment of the wound, failure of the initial operation to prevent infection, or ineffective early treatment of the infection itself. It must be emphasized, however, that in most cases failure of the initial operation was due to uncontrollable conditions, such as a long interval between the receipt of the wound and the admission to the hospital, excessive and prolonged contamination especially in association with bone lesions, or early evacuation with imperfect supervision of the patient and wound.

Every effort should be made to recognize the infection early in its development. If, after the initial operation or in cases in which no operation has been performed, the local examination or the general condition of the patient suggests infection, the joint should be aspirated. If the character or culture of the aspirated fluid indicates pyogenic infection, arthrotomy should be performed. In the case of staphylococci or streptococci there should be no delay. But where there is distention of a joint with turbid fluid, not containing pyogenic organisms, delay is warranted and aspiration may even be repeated. The injection of antiseptic solutions after evacuation of the effusion has met with some success.

Space does not permit a description of the technic of arthrotomy for suppurative arthritis. The appropriate incisions for the various joints and the details of dissection may be found in the chapter on Operation on Bones and Joints in other volumes of Keen's Surgery and in articles mentioned in the Bibliography. One or more incisions should be made, unless an existing incision is so situated as to allow satisfactory drainage; in that event it should be reopened. Continuous drainage is best provided by Willems' method of active movements, especially in the knee-joint. (The details of the procedure are given in a later paragraph.) But if fo. any reason this method cannot be carried out, for instance, by reason of extreme suffering, or considerable bone involve-

ment, the Carrel-Dakin method of chemical disinfection is the best substitute. Moreover, in early cases of non-virulent infection, especially with little bone involvement, success may rapidly follow the inauguration of this treatment. It is evident, however, that the construction of most joints renders it extremely uncertain whether irrigation of the entire joint cavity can be accomplished. Drainage by rubber tubes which is so often practised is objectionable in that the tubes produce pressure necrosis and do not drain adequately. They should never be used in superficial joints, as the elbow or knee. At times they must be employed in deep joints, such as the shoulder and hip. But it must be emphasized that any kind of drain within a joint is harmful and should be avoided if possible.

When cases have not been treated sufficiently early by arthrotomy and active movements or by the Carrel-Dakin method, or have failed to respond satisfactorily to these procedures, a chronic virulent infection may be expected. The articular cartilages and adjacent bone become involved and this renders joint suppuration long and serious. In general, a well-established suppurative process continues until the involved cartilage has been entirely eroded. Moreover, extension of the infection to the cancellous bone of the epiphyses, which quickly occurs if there are fissures or lines of fracture, leads to osteomyelitis which is peculiarly resistant to treatment. In many cases the infection also extends to the soft parts, causing peri-articular abscesses.

In cases which are not progressing satisfactorily under conservative methods resection offers a means of establishing satisfactory drainage, and is, in general, the best method of treatment. After resection the wound is treated by the Carrel method. It may be allowed to close by granulation or, when sterile, may be closed by secondary suture.

Unfortunately, there is no single indication for resection in suppurative arthritis. It is this which makes decision so difficult and often too long deferred. Various factors must be weighed, such as the degree of local infection, the extent of bone involvement, the severity of septic symptoms, and the general resistance of the patient. The same factors must be considered in the decision as to whether resection or amputation should be done.

Amputation must be practised in a certain proportion of cases of prolonged joint infection, especially when there is such a degree of sepsis and diminished resistance that the less radical procedure of resection with the necessarily long after-treatment apparently cannot be supported. Amputation is a life-saving measure where resection has failed or has been too long delayed, but nice judgment is necessary to determine when it is indicated. One is always loath to advise the sacrifice of a limb, and consequently many cases have been lost by persisting too long in more conservative measures.*

* It is of interest to note that Ritter recommends a non-fenestrated plaster bandage in the treatment of suppurative arthritis following wounds by projectiles. His experience comprises 70 cases, with 1 death, no complications referable to the procedure, and no subsequent operations, such as resection. He attributes these results to the absolute rest inducing a delayed absorption, while the permanent pressure produces a local hyperemia analogous to Bier's method of occlusion dressings.

The general treatment of septic joints having been outlined, certain specific details which bear upon individual joints must be considered.

The **knee** is the joint in which the most serious infections are encountered and is one of the joints most resistant to treatment. As Tuffier emphasizes, its anatomic structure alone will explain the frequent failure of irrigation and drainage. "Infection spreads backward sooner or later, and no amount of irrigation of the anterior cavity will affect suppuration in the posterior pouches." Frequently pus finds its way through the back of the joint into the deep portion of the popliteal space and then passes upward or downward along the great vessels, and burrows among the muscles of the thigh and calf. Abscesses also may extend from the subcrural bursa anteriorly between the bundles of the quadriceps, especially between the rectus and vastus externus (Guénard). Among 40 cases of suppuration of the knee-joint seen by Guénard in the course of a year, such migratory abscesses were observed 14 times. Drainage of such abscesses by appropriate incisions is necessary; the occurrence of the abscess in itself does not, as a rule, demand more radical procedures. Of the various methods for drainage of the popliteal space, that advocated by L. C. Abbott is said to be very satisfactory. Through an incision on the inner aspect of the leg below the condyle the popliteus muscle is exposed and separated from the tibia. The space is thus drained with the muscle between the vessels and the drainage tract.

As to the employment of the Carrel treatment for infections of the knee-joint, it is possible to abstract an unpublished article by Chutro on suppurative arthritis of the knee which summarizes his experiences and views.

Lateral incisions are always made and if the Carrel treatment is used traction is employed to relieve constant bony contact and pressure which he believes causes erosion of the cartilage. In 1917 he treated a series of cases with Carrel tubes in the joint and periodic irrigations with Dakin solutions for eight to ten days. The results were 30 per cent. cured with mobility, some up to 90 degrees. Periarticular abscesses were very rare; amputation was necessary in 5 per cent. He noted changes in the synovial membrane and frequently adhesions between opposed surfaces which he believed caused later restriction of motion. Further, he noted that although the wounds were not sterile at the end of eight days, the cases did better in every way under this shorter treatment than those Carreled for three to four weeks. Accordingly, he further limited the time of the Carrel treatment to forty-eight hours, and in this series obtained 60 per cent. mobile knees, though with some limitation of flexion. In some of the cases the repair of the wound was complete in four weeks.

Chutro believes that the pressure of the tubes in the joint irritates mechanically the synovial membrane and provokes a strong reaction; that Dakin's solution produces edema of the serosa; and that these two factors cause desquamation of the superficial cells. The shorter periods of treatment produce correspondingly less irritation. He draws the

broad conclusion that foreign bodies should not be introduced into a joint if mobility is aimed at. After becoming familiar with Willems' method he employed it whenever possible. Thereafter his use of the Carrel treatment was restricted to (1) cases in which there was a lesion of the tibia, which he found always resulted in extreme pain and poor results under the Willems method, and (2) extensive lesions of bone and soft parts.

It must be emphasized that the knee is the ideal joint for the employment of Willems' method. Blake states that functional results are obtained by this method which would be unattainable by any other treatment, and believes that this is due largely to the conservation of the cartilage and synovial membrane by the maintenance of function.

By reason of the gravity of wounds of the knee when complicated by infection radical measures are often indicated at a relatively early stage, the effort being made to control infection though at the sacrifice of joint function. Therefore, when cases have failed to respond satisfactorily to conservative treatment and the local and general conditions are bad and are becoming progressively worse, adequate drainage should be provided. For this, various methods have been practised, among which are: Transverse incision through the ligamentum patellæ; the patella is turned upward, the semilunar cartilages removed, and lateral and crucial ligaments divided, the knee is sharply flexed and held in this position until infection is controlled, when the joint is resected or, if possible, extended. Rankin advocates a similar procedure, but opens the joint by means of a ⌒-shaped incision through the quadriceps tendon which allows the patella to be turned down and gives free access to the subcrureus pouch. Chaput and Guénard advocate patellectomy. Fullerton recommends resection with temporary wide separation of the ends of the bones. Ballance not only resects but removes the posterior margin of the sawn condyles in order that drainage of the posterior portion of the joint may be better ensured. In all of these methods the Carrel-Dakin treatment has been employed advantageously after adequate exposure had been obtained.

Drainage by resection has led to the best results. Not only is drainage thus established, but, in addition, the removal of the articular cartilages and much of the infected bone favors repair, since these tissues are largely responsible for the persistence of the infection.

As Fullerton describes the operation, a U-shaped incision is employed, the patella is removed and the articular ends sawn across, removing in all about 2 inches. A few stitches may be introduced in the middle of the flap, the remainder of the wound being left open. Wide separation of the ends of the bones is obtained by traction through a Thomas splint. The wound is treated by the Carrel-Dakin method. The ends of the bones are not allowed to approximate until infection is completely controlled, and then only gradually, the limb being immobilized in slight flexion. If union has not taken place when the wounds have healed, the case may be operated upon again and the freshened ends brought into apposition as in a clean case.

Resection is indicated when the general condition permits, but in cases of long-standing infection with fever and poor general condition amputation is sometimes advisable. In the lower limb its consequences are less serious than in the upper and the results of delay are frequently disastrous. As Cook states, amputation is the ultimate means of defense and should not be too long withheld.

For persistent suppuration of the shoulder, elbow, hip, and wrist resection is also often indicated in cases which are doing badly. Details of resection, including subperiosteal resection, as well as the proper positions for ankylosis in these joints, are outlined elsewhere.

For the elbow Chutro has recently advocated and practised aperiosteal resection, with good results. He enforces early active movements and aims to obtain a mobile joint. He summarizes his method

FIG. 207.—BACKWARD DISPLACEMENT OF OS CALCIS AFTER ASTRAGALECTOMY. Temporary wiring to retain this position. (Courtesy of Dr. Chutro.)

in an unpublished article as follows: "Osteotomy of the humerus above the epiphysis with removal of the inferior fragment in a retrograde fashion without touching the bones of the forearm and without touching the insertions of the muscles."

For persistent infection of the ankle, especially if there is an infected fracture of the astragalus, astragalectomy gives the best result. Chutro employs an S-shaped incision, beginning above the external malleolus, descending along its anterior margin to the joint, then transversely to tendon of tibialis anticus, thence downward 3 to 4 cm. He urges that the foot should be displaced well backward. To retain the foot in this position Chutro uses temporarily a bronze wire which passes through skin, posterior edge of cuboid, anterior edge of external malleolus, and again through the skin. The projecting ends are twisted and thus fix the

foot in position (Fig. 207). The open wound is treated by Carrel's method. It may be allowed to close by granulation or, when sterile, it may be sutured. "During the course of treatment the foot must be kept at a right angle and slightly inverted. When the patient begins to walk the sole of the boot and heel should be raised on the inner side and he should walk with toes turned inward" (Hughes and Banks). They warn that neglect of these precautions will lead to deformity and disability.

Mobility vs. Stability After Resection.—When adequate drainage has been secured by resection of a septic joint the choice between mobility and stability must be made. If stability is elected, the functional usefulness of the ankylosed joint depends almost entirely upon the angle of ankylosis. With special reference to the relative advantages of ankylosis in a favorable position or a certain amount of motion imperfectly controlled, Osgood states, "that with certain exceptions after septic compound joint fractures, ankylosis in a position favorable for function is a result vastly superior to small degrees of fairly stable motion or large degrees of a more or less flail-like movement, always imperfectly controlled by muscle action. This is, without exception, true with respect to the shoulder-joint, the hip-joint, the knee-joint, and the ankle-joint, for people who must earn their livelihood. One exception is the elbow, which may in a few trades be better even flail than stiff, though it usually involves the wearing of apparatus. One other exception is the wrist, which, with a few degrees of motion, but never flail, may be more serviceable than a stiff joint. It will be noted that both elbow and wrist are non-weight-bearing joints, over which run certain tendons, all of whose attachments need not be disturbed by the excision. The muscular control of the joints may be to some extent thus conserved. Even these exceptions are debatable." These arguments seem sound, and are sustained by such reports as Tavernier and Julifer, who describe numerous cases of flail joints upon which they operated to improve the function of the elbow, shoulder, and wrist. But most surgeons are not as definitely in favor of rigidity after resection of these joints. Their views are to some extent supported by the analysis of large series of cases, such as that of Tuffier. Osgood's recommendations as to the best angle of fixation for the different joints is given in a later paragraph.

Functional Results of Resection.—Tuffier has summarized the late results of joint resections. Based upon the examination of 1810 cases, comprising: 630 elbows, 330 shoulders, 282 knees, 231 astragali, 152 wrists, 122 hips, 29 posterior tarsal joints, 14 anterior tarsal joints, he finds: *Elbow* 49 per cent. solid and with variable degree of mobility; 30 per cent. flail, 20 per cent. ankylosed. *Shoulder* 45 per cent. solid and with variable degree of mobility, 38 per cent. flail, 16 per cent. ankylosed. *Wrist* 64 per cent. solid and mobile to some extent, 36 per cent. ankylosed. *Hip* 30 per cent. solid with restricted mobility; ankylosed 48 per cent. *Ankle* (astragalectomy) 20 per cent. solid with some mobility; ankylosed 70 per cent. In the knee the operation does

not aim at mobility, but rigidity. Ankylosis occurred in 85 per cent. of the cases.

Resection of a joint may be indicated at the primary operation when there is such destruction of the articular surfaces as to preclude saving the joint, or secondarily for severe suppuration to obtain adequate drainage, or remotely, in order to give greater mobility or greater strength to the limb. The cases analyzed by Tuffier were all of the first and second of these three groups.

The technic of resection of the different joints, including the subperiosteal method of Ollier, may be found elsewhere in this work and in the articles referred to in the Bibliography.

Active Mobilization in Purulent Arthritis.—Willems' Method.—In applying mobilization in the treatment of purulent arthritis Willems' original purpose was to secure efficient drainage after arthrotomy. In describing the development of his method he states that he found that there was no system of irrigation which could be depended upon to limit the extension of the infection, not even the Carrel procedure, and that resection solely to ensure drainage appeared too radical. He therefore endeavored to drain the joint by squeezing it out through active movements. His early attempts were convincing. He states that when an infected joint has been opened by unilateral or bilateral arthrotomy, the patient can move the joint without difficulty. With each movement of flexion and extension pus is expelled. This expulsion is the more complete the more extensive the movements and the more vigorous the muscular contractions. When these movements are repeated a sufficient number of times all the secretions are expelled. The suppuration usually lasts for weeks, first profusely, then diminishes to a few drops daily, and finally ceases. For a long time a fistula persists which closes periodically, and must be reopened in order to drain the small quantity of retained secretion. The swelling of the peri-articular tissues persists to some extent until after complete cicatrization. Peri-articular abscesses are practically unknown. The general condition improves very rapidly. Active mobilization thus accomplishes ideal drainage without the assistance of any other measures.

At first mobility is readily maintained. The movements become easier and less painful the oftener they are repeated. The muscles are very slightly affected by the arthritis. The quadriceps and the brachial biceps, which usually undergo rapid atrophy in purulent arthritis of the knee and elbow, remain surprisingly strong. The end of the treatment is usually reached with an almost negligible degree of atrophy.

As soon as the articulation becomes dry a tendency to stiffening is occasionally noted. In order to avoid this danger Willems partially closes the arthrotomy wounds when the suppuration has become markedly diminished, only a small opening being left corresponding to that portion of the wound where the secretion still persists. By this method the mobility can almost invariably be preserved, at least to a great extent; not infrequently it is perfect. Willems attributes the

satisfactory results to limitation of the infection to the synovia as the result of perfect drainage, which militates against its extension to the cartilage and bone.

He admits that all articulations are not equally well adapted to drainage by arthrotomy and active mobilization. The thoroughness of the drainage is proportionate to the more or less extensive range of movements of the joint. From this viewpoint the elbow and the knee, which can perform wide excursions, are the most favorable (Figs. 208, 209). The wrist and ankle, where extension and flexion are more limited,

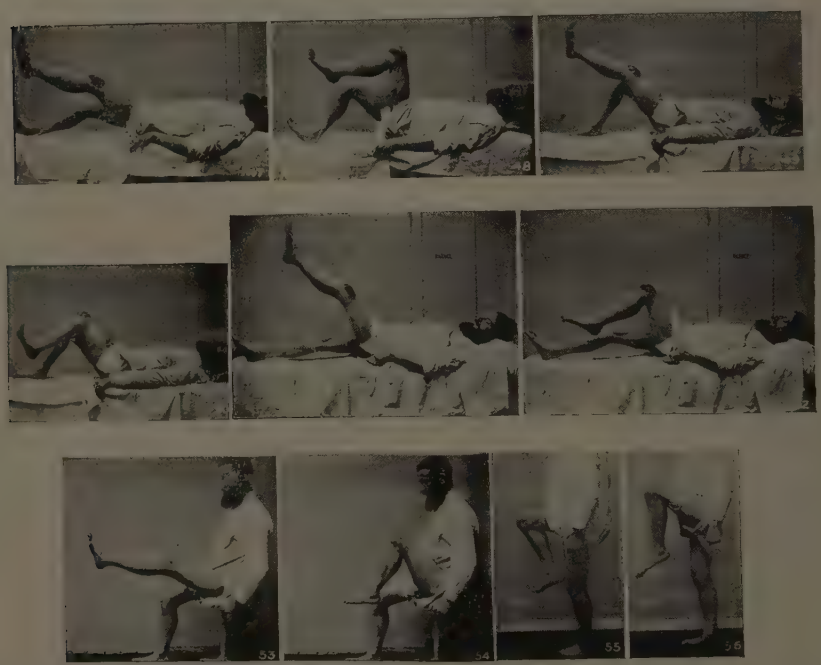

FIG. 208.—MULTIPLE WOUNDS BY PIECES OF SHELL. 47, 48, PURULENT ARTHRITIS OF LEFT KNEE FROM A SMALL WOUND IN THE POPLITEAL SPACE TWENTY-FIVE DAYS AFTER RECEIPT OF WOUND, TWO DAYS AFTER ARTHROTOMY; 49, 50, SEVEN DAYS AFTER ARTHROTOMY; 51, 52, THIRTEEN DAYS AFTER ARTHROTOMY; 53, 54, TWENTY-FIVE DAYS AFTER ARTHROTOMY; 55, 56, SIX WEEKS AFTER ARTHROTOMY. (Willems, in Surg. Gyn., and Obst.)

expel the secretions less thoroughly, and in these joints the method has yielded less rapid and less complete results.

Willems reports 100 cases of suppuration of the knee, with no deaths, no amputation, one resection, 2 cases of ankylosis. The functional results were in general good and in many cases perfect.

Delrez describes the technic of Willems' method as follows: In the cases of serous staphylococcus synovitis it is sufficient to reopen the original incision. In the presence of streptococcus infection classical bilateral arthrotomy is indispensable. The joint must be opened very widely on both sides. The wounds are covered with aseptic dressings loosely applied. No immobilizing appliance is employed. Hot dress-

ings are applied for the first forty-eight to seventy-two hours, changed every two to three hours if considerable joint swelling and local reaction follow the operation.

As soon as the patient wakes he is instructed to begin active movements. His confidence must first be won by having him carry out with the healthy limb the movements which he is to do with the wounded limb. In the case of the knee the procedure is as follows: first the patient raises the entire limb from the bed; he flexes the thigh on the pelvis, then alternately flexes and extends the leg on the thigh. Delrez states that it is a noteworthy fact that although passive movements

FIG. 209.—SUPPURATIVE ARTHRITIS: 3, 4, TWO DAYS AFTER ARTHROTOMY; 5, 6, THIRTEEN DAYS AFTER ARTHROTOMY; 7, 8, TWENTY DAYS AFTER ARTHROTOMY; 9, 10, ONE MONTH AFTER ARTHROTOMY; 11,12, TWO MONTHS AFTER RECEIPT OF WOUND; FIFTEEN DAYS AFTER BEGINNING OF INFECTION; 13, 14, TWO MONTHS AND A HALF AFTER INFECTION. (Willems, in Surg., Gyn., and Obst.)

are extremely painful, active movements cause no inconvenience, the patient complaining of heaviness of the limb, but not of pain. The first sessions are fatiguing, later ones becoming progressively easier. The active mobilization must be repeated at least every hour during the day and two or three times in the course of the night. The patient is gotten out of bed as soon as possible, using his injured arm or leg if the temperature is low and bone lesions do not contraindicate. We have seen cases on Delrez's service walk about with pus escaping from the knee-joint at every step (Figs. 211, 212).

Our own observations of the method are that patients must be urged and almost driven to use the limb. If this is done early little

pain results; if delayed or used only after a long interval motion is painful and restricted. Cessation of movements is usually followed by accumulation within the joint, associated with increased pain and temperature reactions. The method undoubtedly affords a valuable weapon of defense against suppurative arthritis. The application and limitations of the method, as we see them, have been presented in the course of the article.

Ankylosis.—The treatment of deformities with impairment of function resulting from partial or complete ankylosis has been outlined by Osgood in an admirable article which is here summarized: "If the joint has been the seat of a serious infection, it is usually unsafe to undertake considerable operative procedures for from six months to a year after the subsidence of the sepsis. Judgment as

FIG. 210.—DELREZ'S METHOD OF PRODUCING MOBILIZATION OF THE KNEE WHERE ACTIVE MOVEMENTS ARE IMPOSSIBLE BY REASON OF A WOUND OF QUADRICEPS.

This was a case of suppurative arthritis of knee.

to when these surgical attempts are safe is always difficult. Massage more or less violent may serve as a guide. If, after such massage, a definite recrudescence of the cardinal signs of inflammation occur, it is usually unsafe. The absence of this reaction is suggestive of sufficient quiescence to make operation possible.

"The first determination is whether mobility or ankylosis in a favorable position for function is to be sought. It must be recognized, however, that restoration of perfect mobile function is rarely possible in these cases. Only the hip and the elbow should be attempted, the hip more rarely than the elbow." The various methods of arthroplasty cannot be described.

"The great majority of the cases in which decision between attempts

at mobility or ankylosis in a favorable position must be made occur in war surgery among working men whose wage-earning capacity must be the controlling factor in this decision. It is a matter of constant surprise to find how little disturbance of wage-earning capacity is caused by a completely stiff joint in a favorable position for his trade. Generally speaking, the shoulder should be fixed in 50 to 80 degrees abduction, in a plane about midway between the anteroposterior and lateral planes of the trunk, that is, the elbow should come somewhat forward. A single elbow should be fixed in such position that the angle which the forearm and upper arm enclose is about 100 degrees, that is, a little more obtuse than a right angle. Where both elbows are ankylosed, one

FIGS. 211, 212.—PATIENT WALKING WITH PUS EJECTED AT EACH STEP FROM OPENING INTO JOINT. ARTICULAR SURFACE OF FEMUR VISIBLE WHEN KNEE IS FLEXED. (Operator Debrez La Paune.)

should be a little more than a right angle (100 to 110 degrees), the other a little less than a right angle (70 to 80 degrees). In both these positions the hand should be midway between pronation and supination. The wrist should be in dorsal flexion. The hip should be fixed in 5 to 10 degrees abduction, 5 to 10 degrees outward rotation, and 10 to 20 degrees of flexion. The knee should be fixed with varying degrees of flexion up to 45 degrees, depending on the occupation. The ankle gives best function in right angle dorsal flexion, with perhaps a little equinus to allow for the heel of the shoe. We are inclined to believe that in the vast majority of cases, except possibly the elbow-joint,

ankylosis in a favorable position should be the operation of choice in war surgery in case of terminal joint deformity."

"Partially Ankylosed Joints With or Without Deformity.— The problem here is the restoration of as large a range of mobility as possible. In joints which have been the seat of an infection gentleness of manipulation is the rule to be followed almost without exception. 'Brisement forcé' under an anesthetic is rarely successful in gaining greater range of motion and is often provocative of a lighting up of the old infection. It is to be thoroughly discouraged. Light massage, mechanotherapy, and hydrotherapy are the first procedures, accompanied by gentle passive movements and the stimulation of the patient to carry out active movements. These latter are by far the most important. Between these treatments apparatus is often of great advantage, both that which retains motion gained in the direction desired and that which by elastic pull constantly exerts gentle traction in the appropriate lines. Recovery is gradual and often seems to the patient slow and tedious. If his endeavor to gain motion is coupled with the stimulation of a definite occupation, which accomplishes a purpose of some sort, time passes more quickly, motion increases automatically and almost unconsciously. Tailoring, carpentry, leather working, brace making, printing, basket making, and farming are all easily adapted occupations."

As a result of the admirable organization of the Orthopedic Department of the United States Army adequate facilities for reconstruction on the lines specified were provided in our hospitals.

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CHAPTER XXII

ORTHOPEDIC SURGERY IN CIVIL LIFE

By Robert W. Lovett, M. D.,
Boston

ARTHRITIS DEFORMANS

In this condition and in cases of more acute arthritis supposedly of infectious origin, recent progress indicates the need of searching for the focus which lies at the root of the absorption, with a view to its removal. This focus is most often to be found in the teeth, tonsils, sinuses, genito-urinary tract of the male, in the uterus and appendages in the female, and occasionally in the appendix or intestines. If such focus can be detected and removed, the prognosis of the case becomes immediately better, but in my own opinion the removal of the focus should be followed by the administration of a vaccine, preferably autogenous, over a period of considerable duration. The removal of teeth and tonsils for the relief of the arthritis very often proves disappointing, but if followed by the use of the vaccine satisfactory results seem to follow in a larger proportion of cases. The matter of vaccine administration is dealt with elsewhere.*

Failing to discover an obvious source of pyogenic infection, it becomes advisable to investigate the digestive process with great care, with a view of correcting any abnormality, especially in the direction of intestinal fermentation. Investigation of the general condition of the patient becomes of unusual importance in the more recent point of view with regard to the correction of abnormal conditions if they exist. The glands of internal secretion are not to be overlooked and chronic traumatism from strain is a factor in certain cases.

The competent surgeon is no longer content to make the diagnosis of arthritis and trust to drugs, hydrotherapy, massage, and braces to effect improvement, but regards the joint manifestations as symptomatic of some radical disturbance of normal processes, which defect, if possible, must be located.

TUBERCULOSIS OF JOINTS

Diagnosis.—In a series of a good many hundreds of cases of joint tuberculosis and other abnormal joint conditions under my own observation the von Pirquet skin test has proved to be unexpectedly reliable. A series of 350 cases was investigated by Robertson at the Children's Hospital, Boston. These children were all under twelve, and included cases of tuberculous joint disease and other children under orthopedic

* See chapter on Serum Treatment, by Dr. John A. Kolmer.

treatment who were presumably non-tuberculous. The conclusions reached have been fully substantiated in the five years succeeding the analysis mentioned. Robertson's[1] conclusions were as follows:

In all cases having clinical evidence of surgical tuberculosis, either in bone or soft tissues, 2.9 per cent. showed negative von Pirquet reactions. In those cases not showing definite clinical evidence of tuberculosis, although some showed enlarged anterior cervical glands and

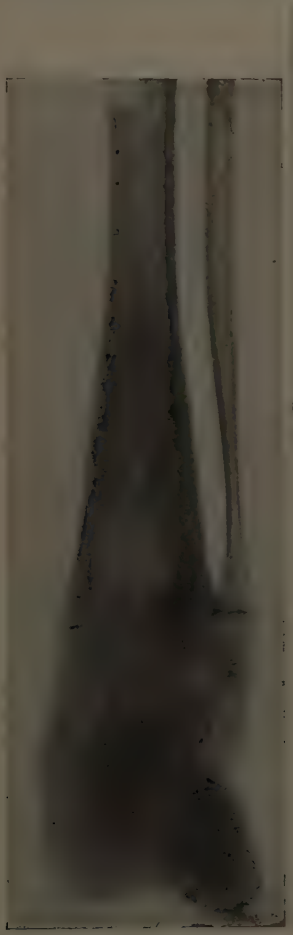

FIG. 213.—TUBERCULOSIS OF TIBIA.

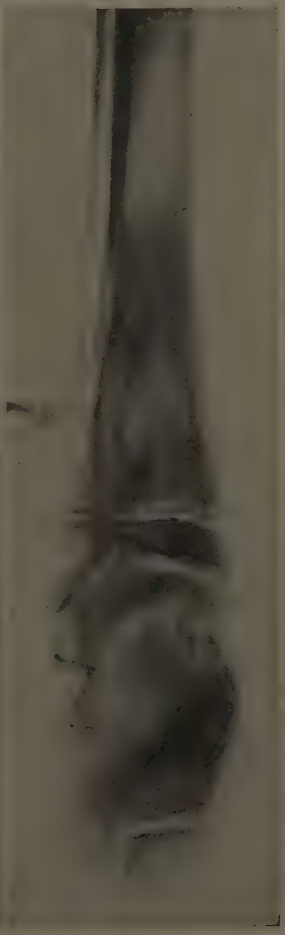

FIG. 214.—OSTEOMYELITIS OF TIBIA.

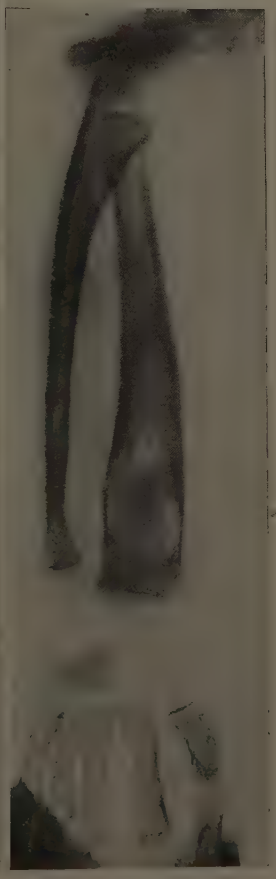

FIG. 215.—OSTEOMYELITIS OF RADIUS.

others gave a family history of tuberculosis, 14 per cent. showed positive cutaneous reactions.

In the apparently non-tuberculous cases the reaction is more frequently negative in the younger children, as seen from the following:

0– 4 years, 48 cases. Positive reactions in 10 per cent.
4– 8 years, 61 cases. Positive reactions in 14.5 per cent.
8–12 years, 40 cases. Positive reactions in 17.5 per cent.

The reaction may be regarded as specific, and the fact that it is positive in a moderately small percentage of clinically non-tuberculous children does not outweigh its value as a diagnostic test. From the above figures it must be concluded that the von Pirquet reaction is fairly reliable in children under twelve years of age, but that it has less significance where the patient shows enlargement of the anterior

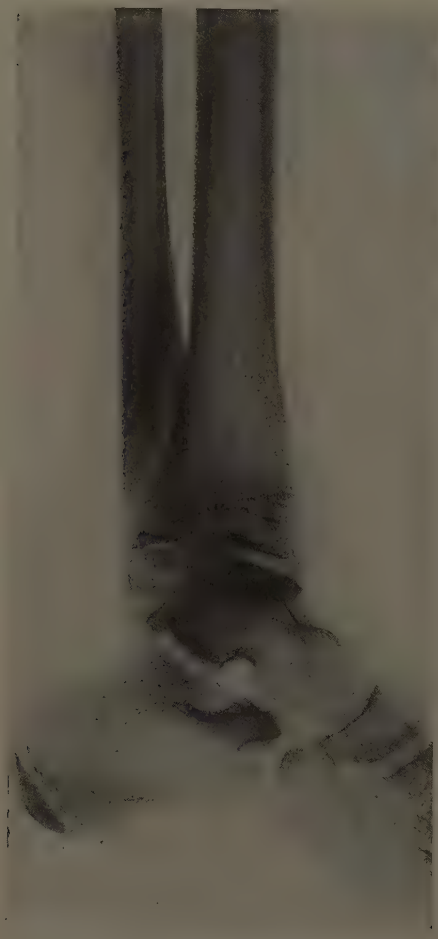

Fig. 216.—Osteomyelitis of Fibula.

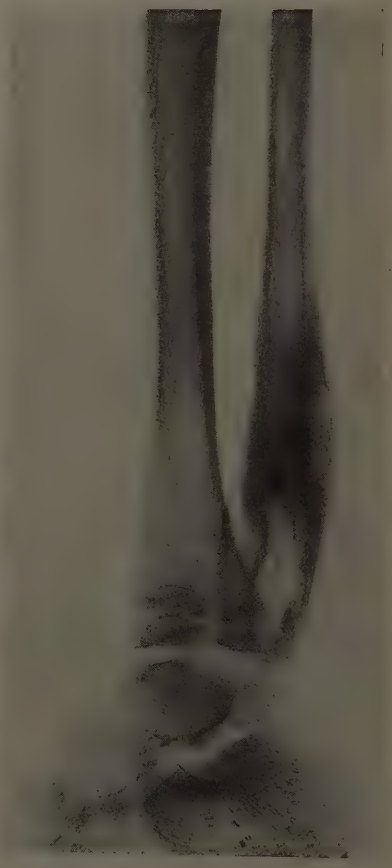

Fig. 217.—Syphilis of Fibula.

cervical lymph-nodes or gives a family history of tuberculosis. It is stated that the reaction may be absent where severe toxemia is present,[2] and this fact would seem to be borne out by the two negative reactions occurring in two of the above-mentioned cases, one of tuberculous hip and one of tuberculous spine.

There is a much greater proportion of positive reactions in apparently non-tuberculous cases than of negative reactions in those

clinically tuberculous. These figures have been fully borne out in the succeeding years in the orthopedic service at the Children's Hospital.

With two negative von Pirquet reactions in a child with suspected tuberculosis the diagnosis of tuberculosis is not made, with the following one exception: if an extensive destructive lesion, clinically tuberculosis, is present, yet this reaction is negative, it is borne in mind that the child may be so saturated with absorptive products that it fails to react. In such cases the prognosis is regarded as distinctly poor. In other cases, however, of joint affection with a negative tuberculin skin reaction, the joint is treated on general principles, the case is kept under observation, and in the great majority of cases the patient with a negative von Pirquet reaction proves by the later clinical course not to have had joint tuberculosis.

x-Ray Diagnosis.—There has been a great deal of loose interpretation of radiographic plates in the matter of diagnosticating tuberculous bone or joint disease. As a matter of fact, the focal lesions of osteomyelitis resemble bone tuberculosis so closely that the diagnosis often cannot be made from the plate. There is occasionally found a proliferative form of bone tuberculosis not to be differentiated from pyogenic osteomyelitis by the x-ray plate. Tuberculosis from the radiographic standpoint is a low-grade process, essentially destructive, but with some formative activity. Pyogenic infections, on the other hand, are generally largely formative, but also destructive. With the variation in these two elements the picture often becomes confusing, and a positive diagnosis from the x-ray plate is in many instances distinctly hazardous, especially in cases of focal lesions of the type of the so-called "Brodie's abscess." These statements rest on a considerable series of cases observed by Prof. S. B. Wolbach and myself, as yet unpublished, where the plates were analyzed, the patient subsequently operated on, and a microscopic diagnosis made.

Heliotherapy in Tuberculous Joint Disease.[3]—Cases of joint tuberculosis systematically exposed to the sun's rays, even as far north as New England, make, on the whole, better progress than those not so exposed. The matter has been fully described as practised in Switzerland at high altitudes, and very favorable results reported, but the interest to the American surgeon lies in its use in the neighborhood of large cities in the varying ranges of climate presented by the United States.

The sun treatment may be applied (1) either to the whole body or (2) to the affected region. (1) Exposure of the whole body should be begun gradually; on the first day the feet and half-way to the knee should be exposed for five minutes, the rest of the body being covered. On the second day the knees are included in the exposure, then the thighs, abdomen, chest, and arms, in sections each for five minutes; the time of exposure may then be increased. With this technic there is practically no danger of sunburn even to a delicate skin. When the body has once been gradually accustomed in this way to the sun the exposure may continue to be increased up to practically the whole day.

FIG. 218.—SUN TREATMENT BY LENS. (Thézae Porsmeur method. Lovett, Jour. Amer. Med. Assoc., April 3, 1920.)

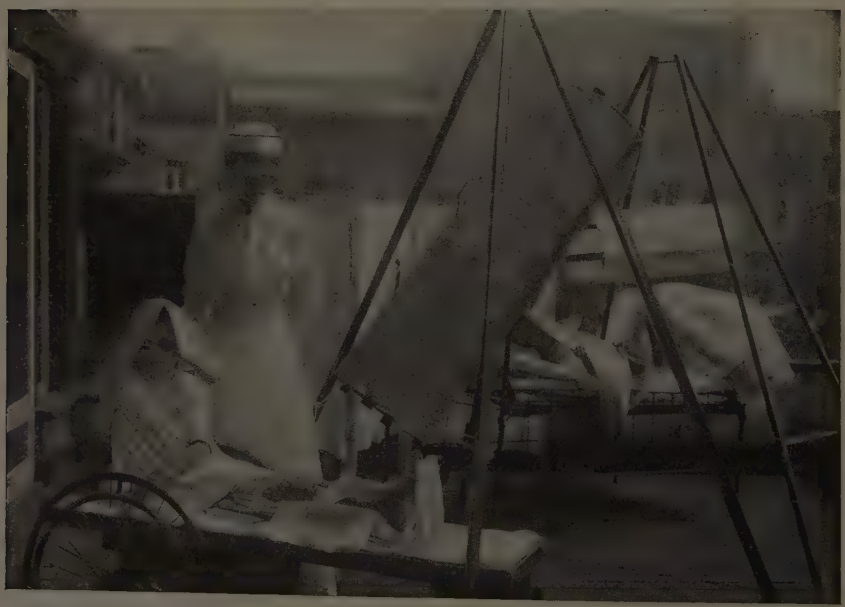

FIG. 219.—SUN TREATMENT BY LENS. (Thézae Porsmeur method. Lovett, Jour. Amer. Med. Assoc., April 3, 1920.)

For six years the children at the New England Peabody Home, an institution for crippled children, have been thus exposed daily from fairly early in the spring until late in the autumn. The skin becomes pig-

mented and much more vascular, sinuses often heal which have persisted for years, the general condition in nearly all cases improves, and the tuberculous process, as a rule, becomes milder. The progress of these cases is very much more satisfactory than before this was done. Unfavorable local or general effects have not occurred. (2) Local exposure is merely a modification of the method mentioned, with the rest of the body protected, and follows practically the same rules.

A method of local exposure has just been introduced from France,[4] in which the sun's rays are passed through a double convex lens of glass,

FIG. 220.—BRADFORD'S ABDUCTION SPLINT FOR TRACTION IN HIP DISEASE. (Bradford and Lovett, "Orthopedic Surgery.")

30 cm. in diameter, with a focal length of 72 inches. The part of the patient to be exposed is placed in the direct path of the rays passing through the lens about half-way between the lens and the focal point. At this point there is no danger of burning, and the heat decreases as one approaches the lens and increases toward the focus. The rays are apparently active when passed through glass, and increased rapidity of healing in sluggish tuberculous wounds has been noted in most of the cases observed under treatment by this procedure. It has a dis-

tinct field of usefulness in being applicable through an open window or in winter. The circle of light on the patient's skin should be from 3 to 5 inches in diameter. The initial treatment should be for about five minutes, and the duration should increase progressively at the rate of about five minutes a day, up to twenty or thirty minutes.

The Bradford Abduction Hip Splint.[5]—The traction splint devised by Bradford for the treatment of tuberculosis of the hip possesses

FIG. 221.—ABDUCTION SPLINT APPLIED. (Bradford and Lovett, "Orthopedic Surgery.")

advantages over most splints, as it holds the affected leg in abduction throughout the disease, thus counteracting the tendency to adduction, so troublesome in most cases. Countertraction is furnished by iron bands instead of straps, and it therefore furnishes better fixation. Clinically it furnishes a better series of ultimate functional results than I have seen from any other method. It is an adaptation of the Thomas knee splint, furnished with traction and a padded horn to keep the diseased leg abducted.

CEREBRAL SPASTIC PARALYSIS

Treatment.—The later tendency of opinion among representative orthopedic surgeons has been away from the performance of the complicated and difficult procedures of the division of the posterior nerve roots as advocated by Förster,[6] the division of the motor nerves supplying the spastic muscles as practised by Stoffel,[7] and the infiltration of the nerve with alcohol. The weight of opinion is to the effect that properly planned tenotomy is, of all the procedures, the one followed by the largest proportion of satisfactory results. Whatever operation is performed must be regarded as merely preliminary to the real treatment, which consists of muscular re-education. When one examines these cases one finds in most cases among the spastic muscles many which are weakened, and these must receive great attention and be developed. The flexors are in all cases stronger than their antagonists, the extensors, and the rebalancing of the muscles by the development of the extensors becomes our chief problem. Stretching the contracted and spastic muscles is undesirable because it is a form of exercising a muscle to overcome its contraction, and a thorough course of stretching will lead to a most undesirable overdevelopment of the flexor muscles, whose power we are anxious to minimize. The best form of muscular re-education consists in gently aiding the patient by gentle manual assistance to perform repeatedly, *e. g.*, an extension of the elbow, that is to say, by the use of the extensor muscles. Rough handling and strong pulling excites muscular irritability and makes the muscles more spastic and irritable. Combining such gentle exercises as described with exercises in balance, rhythm, and co-ordination in many of these cases very satisfactory results are to be obtained. The keynote to treatment lies in recognizing that operation is not treatment, but merely opens the way to it; that there is much muscular weakness, and that gentleness accomplishes much more than force.[8]

INFANTILE PARALYSIS

Pathology.—The great prevalence of infantile paralysis in the United States in 1916 and the years preceding has made our knowledge of the pathology of the affection much more precise.

Anterior poliomyelitis is to be regarded as an infectious disease accompanied in a certain proportion of cases by paralysis. Paralysis is not essential, but accidental, and the proportion of cases in which it does or does not occur is at present undetermined, but most of those who have carefully studied the epidemiology of the disease believe that the so-called abortive or non-paralytic form is very common, possibly more common than the paralytic form. The infectious agent which is the cause of the affection, having entered the system, shows a particular affinity for the cerebrospinal axis, on which it inflicts special injury, greatest in the spinal cord, but only to a less extent in the brain. The significant pathologic changes in the cord are a perivascular infiltration of the vessels supplying the gray matter, edema, punctate or

larger hemorrhages in the anterior horns, degeneration or necrosis of the nerve centers, and a widely distributed meningitis. Commensurate changes also occur in the medulla and brain. The posterior nerve-root ganglion is also involved in the process, and in experimental pathology is the first of the structures to show changes. The clinical expression of these processes is a widely distributed and erratic motor impairment, accompanied in most cases at the outset by marked tenderness over the affected area. The cause of this motor impairment is to be attributed to one or more of the following pathologic conditions which exist:

1. A mechanical anemia of the motor cells in the affected areas of the cord results from the obstruction of the vessels from the perivascular

Fig. 222.—Muscle Chart of the Patient Shown in Fig. 223.
The normal muscles are not shaded; the partly paralyzed muscles are shaded with coarse lines. The wholly paralyzed muscles are closely shaded. (Lovett, "Treatment of Infantile Paralysis.")

infiltration. Such cells may recover or go on to necrosis, depending on the extent and duration of the obstruction. If the effusion is soon absorbed, the blood returns to the cell and it resumes its function.

2. The edema of the affected part of the cord, which is a prominent but temporary feature, interferes with the motor function in the edematous area.

3. The hemorrhages, if in the neighborhood of motor cells, may abolish their function.

4. There is perhaps a direct toxic action of the virus on the motor cells, causing their destruction.

If the patient lives, the perivascular infiltration and edema subside gradually or quickly, and the hemorrhagic products are absorbed, leaving behind areas too much damaged to recover, which are converted into focal scleroses. The sequence is, then, first, an acute hemorrhagic myelitis; second, a convalescent myelitis with returning power; third, a cord in the motor area of which are scleroses, all stages accompanied by more or less motor impairment.[9]

FIG. 223.—ABDOMINAL PARALYSIS COMBINED WITH EXTENSIVE LEG PARALYSIS.
The affected muscles are shown on the chart in Fig. 222. (Lovett, "Treatment of Infantile Paralysis.")

Clinical Phenomena—Distribution.—A more careful examination of cases examined shows that the distribution of the paralysis is not what former tables have shown. In 1323 cases analyzed after the New York epidemic the distribution was as follows:[10]

	General distribution in the order of relative frequency.	
	New cases.	Old cases.
Both legs	338	127
One leg	302	85
Both legs and both arms	127	55
Both legs and one arm	101	43
One arm	83	19
One arm and one leg, same side	38	13
One arm and one leg, opposite sides	29	7
Both arms	33	4
Both arms and one leg	20	8
Girdle cases	57	1
Facial alone	38	1
Total	1166	363

The abdomen and neck are involved much more frequently than is generally supposed. In the same series they may be tabulated as follows:

Involvement of Abdomen, Back, and Neck

	1916 cases.		Old cases.	
	Number.	Per cent.	Number.	Per cent.
Abdomen	686	72.3	168	44.8
Back	128	13.5	55	14.6
Neck	103	10.8	27	7

The relative affection of individual muscles is of importance.

Lower Extremity.

	Total.
Tibial, anterior	246
Tibial, posterior	206
Extensor proprius hallucis	160
Extensor longus digitorum	163
Peroneals	156
Gastrocnemius	98
Hamstrings	42
Quadriceps	55
Hip adductors	46
Toe flexors	70
Iliopsoas	15
Hip abductors	20
Gluteus maximus	29
Totals	1306

Upper Extremity.

	Total.
Anterior deltoid	39
Posterior deltoid	33
Opponens pollicis	43
Outward rotators	16
Rhomboids	9
Latissimus dorsi	16
Biceps	9
Triceps	12
Lumbricales	15
Trapezius	10
Pectoralis major	19
Interossei	19
Thumb extensors	8
Serratus magnus	1
Wrist flexors	8
Thumb flexors	9
Supinators	10
Finger extensors	6
Pronators	9
Wrist extensors	8
Finger flexors	5
Totals	304

Scoliosis.—The significance of recognizing abdominal paralysis is shown, for example, in connection with lateral curvature of the spine, with which it is often associated. In recent cases involvement of the abdomen occurred in connection with lateral curvature in 75 per cent. of the cases. Apparently the most frequent cause of serious scoliosis occurring in this disease is unilateral involvement of the abdominal muscles. Any affection of the abdomen in the early stage should make one watchful for scoliosis at a later stage.

Relation of Total to Partial Paralysis.—In 1323 New York cases in 948 patients recently paralyzed there were 2353 totally paralyzed muscles, an average of $2\frac{1}{2}$ totally paralyzed muscles per individual. In 375 old cases there were 1622 totally paralyzed muscles, an average of $4\frac{1}{2}$ totally paralyzed muscles per individual. Total paralysis was, therefore, relatively more frequent in old than in new cases. The proportion of total to partial paralysis in the whole group of new cases is less than in the whole group of old cases. When this matter is analyzed it is found that it is due almost wholly to conditions in the muscles of the leg and foot, in which the proportion of total to partial paralysis is very much higher in old than in new cases, whereas in the hip and thigh it is relatively less in the old cases than in the new. The interpretation that seems best to fit the fact is that in the months following the attack, when walking is begun, the activity of weight bearing constitutes such gross overuse

FIG. 224.—EXTENSIVE PARALYSIS OF TWO YEARS' DURATION SHOWING ABDOMINAL PARALYSIS, SCOLIOSIS, TALIPES EQUINUS ON RIGHT. PARALYSIS OF BOTH LEGS.
(Lovett, "Treatment of Infantile Paralysis.")

FIG. 225.—CLOTH CORSET FOR SUPPORT OF ABDOMINAL OR BACK MUSCLES.
(Lovett, "Treatment of Infantile Paralysis.")

of the leg muscles that not only are they kept from improving but also that weakening is converted to total paralysis. This is only to be expected if one looks at the facts. The lowering of power in the weakened muscles of the leg is considerable, as the following will show: The records of 49 cases of leg paralysis were taken consecutively from the files for analysis as to the degree of involvement in the different leg muscles, as shown by the spring balance test.[11] The power remaining in each of the affected groups of the lower extremity ranged from 28 to 52 per cent., with an average of 41 per cent. (Below the knee the average of all groups was 34.6 per cent.; above the knee, 41 per cent.)

Whatever may be said in its favor, walking with a muscle which is reduced to 30 or 40 per cent. of its normal power is a very serious tax on that muscle's endurance, and however much one may believe in exercise, the use of such muscles for weight bearing and walking is not desirable from what we know of the physiology of muscles. These data taken together bear out a perfectly clear conviction that walking

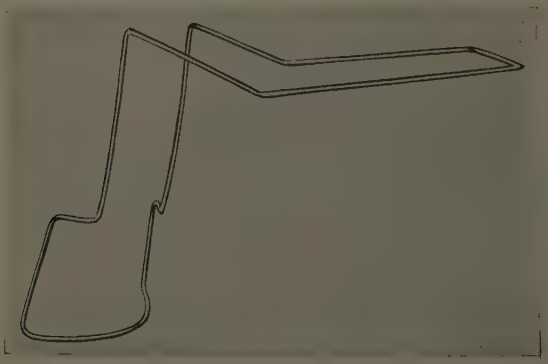

Fig. 226.—Platform Splint for the Right Arm Made Out of Wire Before Covering. (Lovett, "Treatment of Infantile Paralysis.")

to any extent, with or without braces, in the first year after an attack of infantile paralysis not only tends to delay the improvement of partly paralyzed muscles, and is liable to set a limit to their final restoration, but may also change them from the class of partly paralyzed to totally paralyzed muscles.

Treatment.—The following considerations, the outcome of recent observations and analysis, are of importance in enabling us to formulate modern treatment. The existence of *tenderness* may be assumed to be evidence of the persistence of some degree of the acute process in the cord. The use of massage and manipulation while tenderness lasts will, as a rule, make it more acute and prolong it indefinitely. No matter how long the tenderness may legitimately continue, active treatment should not be begun until it has practically disappeared.

Warm saline baths, which have probably been in use toward the close of the acute period, should be continued daily. The affected limbs should never be chilled, but warmly protected. A general phys-

ical examination is desirable, as some degree of cardiac involvement is not unknown. Attempts to prevent deformity should continue.

Muscular weakening is much more common than total paralysis. This must necessarily change our conception of treatment, for the condition is not to be regarded as a more or less hopeless loss of power,

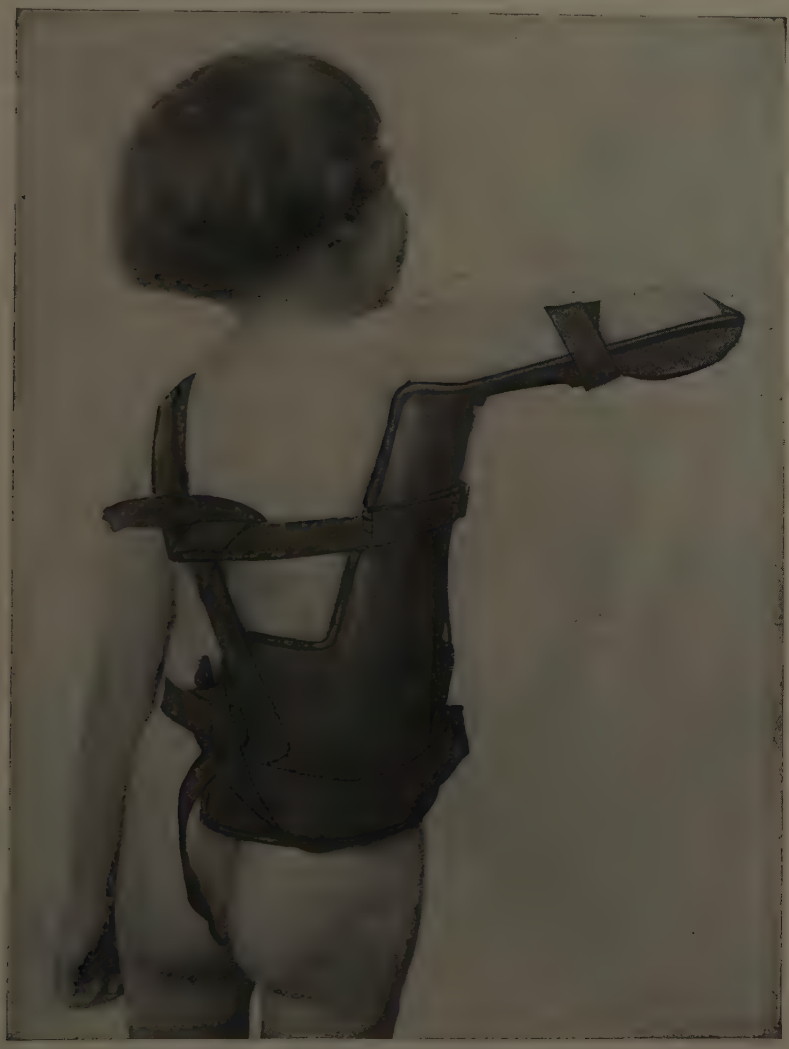

FIG. 227.—PLATFORM SPLINT (SEE FIG. 226) FINISHED AND APPLIED.
(Lovett, "Treatment of Infantile Paralysis.")

but as a muscular weakening with perhaps some total paralysis. If the paralysis were, for the most part, total and hopeless, we should resort to braces and not restrict activity, for there would be no use in doing so. But with a weakening rather than a total paralysis, it should obviously be our effort to strive to strengthen the weakened muscles.

Spontaneous improvement does not cease at the end of about six months, as we formerly believed, but continues for at least two years and probably longer, although it is more rapid in the first year than later. This fact is of importance in encouraging us to feel that we have an asset strongly in our favor during these two critical years.

Fatigue is a detrimental factor of the highest importance to convalescent muscles, and in weakened ones fatigue is brought about with surprisingly little activity. Fatigue of a seriously harmful character

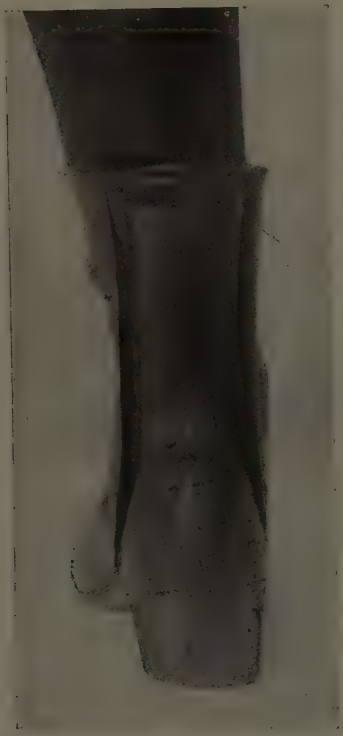

Fig. 228.

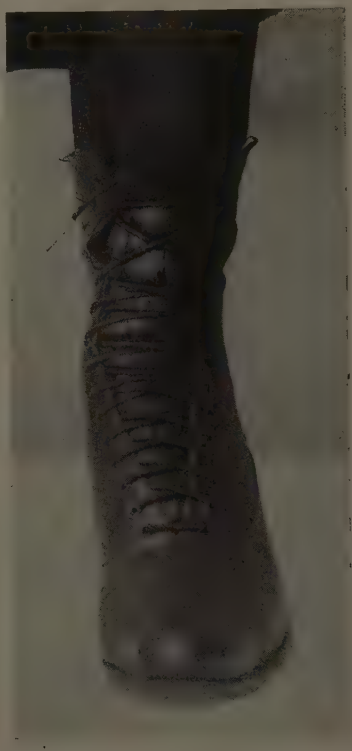

Fig. 229.

Fig. 228.—Retention Brace for Foot Drop of Thin Iron Strips Placed Between the Layers of the Boot and Not Showing Much. At the Bottom the Strips are Turned Inward and Fastened to the Heel. In This Figure the Course of the Strips is Shown by Dark Lines, but They are Really Covered by Leather (see Fig. 229).
Fig. 229.—Brace Shown in Fig. 228 in Use.

(Lovett, "Treatment of Infantile Paralysis.")

can be caused not only by walking too much but also by the overuse of therapeutic exercises, and especially by heavy or prolonged massage. Not only may fatigue and overuse delay the favorable progress of convalescing muscles but also may lead to a permanent loss of power and to permanent and irremediable muscular stretching. The surgeon assumes a serious responsibility who allows walking to any extent in the first year, except in cases which are too grave to warrant much hope of recovery; and even in these cases he must be very skilled in prog-

nosis if in the first months after the attack he can forecast the future of all such cases. The avoidance of fatigue is the keystone of our arch. Probably the most dangerous cases, so far as muscular recovery goes, are the cases with paralysis so slight that the patients walk with fair facility and a slight or moderate limp. It is very difficult to induce the parents to keep these children off their feet for from three months to a year, which must often be done if complete recovery is to be our aim, and these are the cases in which such recovery may often be obtained.

Braces and *apparatus* are not what one would desire to put on a weakened leg when one is striving to secure muscular development. They are heavy, they induce an unnatural use of the leg, they prevent free activity, and the bands and lacings constrict the muscle. On the whole, they favor muscular atrophy; but there is no evidence to show that they increase shortening of the affected limb. Any one will grant that, other things being equal, a brace is undesirable. But more undesirable than the use of braces is the acquirement of deformity, the stretching of muscles, and the loosening of joints from not using them when necessary. The only statement to be made is that braces should not be used unnecessarily, but that they should be used when needed; that they are not in anyway therapeutic, but protective and conservative, and that the so-called "brace treatment" of this stage of infantile paralysis is a misnomer, because to put on a brace is no more treatment of the disease than is the use of crutches in the treatment of fracture of the leg.

There are three measures which are to be remembered at this point as aids to muscular development. The first of these, *massage*, stimulates circulation, tends to preserve muscular tone, and promotes the removal of waste products. Properly controlled, it is of use; in excess or unskilfully given, it is dangerous and harmful.

Electricity depends for its vogue largely on tradition. By some it is advocated, by others decried. In mild cases it is undoubtedly harmless and perhaps beneficial. On the whole, it has done great harm and caused many needless cripples, because it has been administered on a large scale and often very loosely given, while methods of treatment universally acknowledged as useful have not been used; and the parents have been lulled into a false security, thinking that adequate treatment was being pursued, while invaluable time was being lost and disabling deformities acquired.

Muscle Training.[12]—The third of these measures, in my own opinion, is the keynote of modern treatment of infantile paralysis. It is an application of physiology and anatomy to compensate for a pathologic lesion. The order is given to use a certain muscle and, if necessary, the patient is aided by the surgeon in performing the prescribed movement. This is repeated several times at intervals of a few seconds, but never to the point of fatigue. In the stronger muscles the movement should be performed without assistance by putting the limb in a position which gives a favorable leverage for the motion. Muscle training is harmful if inaccurately carried out, *because a child will inevitably*

use the strong muscles in any movement rather than the weak, and if they are continually exercised they become stronger, while the weak remain as they were. Thus muscular balance is made worse and deformity results. A knowledge of functional anatomy is required on the part of the one who prescribes the exercise. This required knowledge is not, as a rule, possessed by the ordinary masseur or masseuse, and the formulation of the exercises should be done by the physician or by a highly trained assistant.

Diagnosis.—The first requisite for adequate and scientific treatment in this as in other affections is an accurate diagnosis, and such a diagnosis in infantile paralysis demands an examination of every available muscle or muscular group in both arms, both legs, neck, back, and abdomen. It must be determined which muscular groups are normal, which are weakened, and which wholly paralyzed. The patient should first be made to walk if he can, as in walking muscular function can be observed and gross defects defined as in no other way. Then the voluntary contractile power of the different muscles and muscle groups should be estimated by directing certain movements and seeing if there is response, and whether that response is normal or weak. The stronger tests should be used first; next, when the conditions of movement are easier, those in which the weight of the member to be tested is partly eliminated by position; lastly, the lowest grades of muscular power may be detected by slinging the limb by means of a bandage. In the severe cases the examination may be made with the patient in a warm saline bath. The buoyancy of the water enables very weak muscles to act which under ordinary conditions would appear to be without function. To find the faintest possible trace of power is of importance in prognosis. It must be remembered that muscles act in groups (synergically) and that the paralysis of one muscle alone is rare.

In the case of babies the voluntary activities of the child must be watched and reflex stimulation used to provoke the various movements with the child held in different positions, but such examinations are not accurate and take much time. In general, an adequate examination under the most favorable conditions of co-operation and intelligence on the part of the patient will consume at least thirty minutes and often more.

The paralyses most often overlooked are those of the face, which are not important, and those of the neck and abdomen, which are of great importance from a prognostic point of view, because the latter when unilateral is the most frequent cause of scoliosis in infantile paralysis, which is a very serious complication. In cases with abdominal weakness a supporting cloth corset should be worn from the outset. Paralysis of the shoulder is often not clearly diagnosticated anatomically. It is important that the relative involvement of shoulder and scapular muscles should be clearly recognized. The use of a wire platform splint is desirable in all cases of involvement of the deltoid muscle, which has proved much less resistant to treatment since this method has been employed.

Treatment.—Correction of deformity must be accomplished before mechanical or operative treatment can be effective.

Equinus Deformity of Foot.—This is, of all the deformities of infantile paralysis, the most frequent, not only because at the ankle the paralysis is more common and more severe than elsewhere in the body, the anterior muscles being most often involved, but because during the acute attack the child is too often allowed to lie with the bedclothes holding the foot in plantar flexion, and in sitting the foot hangs and continues in this same position of dropping, so that the posterior muscles become contracted and the anterior muscles stretched.

A means of correcting it, which has proved most efficient, is to put on a plaster-of-Paris circular bandage reaching from the toes to just below the knee. In putting this bandage on the leg is fully flexed on the thigh in order to relax the gastrocnemius muscle and allow as much dorsal flexion of the foot as possible. When the plaster has become dry, which takes about twenty-four hours, an elliptic piece is cut out over the front of the ankle-joint in the flexure between the foot and the leg, embracing about two-thirds of the circumference of the cast at this point. A webbing loop is then put around the foot and another around

Fig. 230.—Method of Stretching Contraction of the Tendo Achillis. (Lovett, "Treatment of Infantile Paralysis.")

the top of the cast, and these two webbing loops are connected by another webbing strap furnished with a buckle, by which continued tension may be made upon the foot, pulling it into dorsal flexion with any desired degree of eversion or inversion of the sole. In recent cases this method of treatment will correct the deformity often in five or six days, and in older cases often within two or three weeks.

Deformity of the Knee.—There are three deformities found at the knee in infantile paralysis: (1) Flexion deformity, (2) knock-knee, and (3) hyperextension of the knee.

With regard to *flexion deformity*, this condition has proved much less troublesome since the method of wedging to be described was adopted, a method originally adopted to straighten the flexed knees of chronic joint disease. The deformity is due to the predominance of the flexor muscles over the extensors, with the contraction of the knee in a bent position as a result. This deformity may or may not be accompanied by talipes equinus and hip flexion, although the association is frequent. It may occur early in the disease, in this case generally being acquired during the tender stage, or it may appear later as a result of the predominance of the posterior muscles. In this procedure

a circular plaster is applied to the leg in the deformed position, reaching from the groin to the toes. It is made rather heavy over the knee, and after it has dried a transverse division of the plaster is made at the level of the knee covering the posterior two-thirds of the plaster; that is to say, a transverse division of the plaster on its posterior aspect. This slit is then widened by being wedged open by a thin piece of wood,

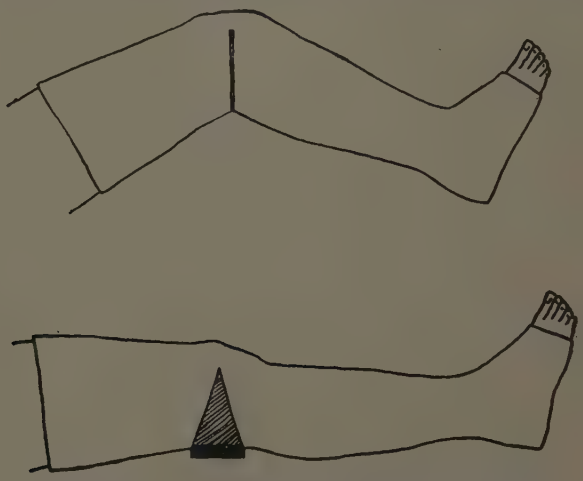

FIG. 231.—METHOD OF WEDGING KNEE FOR FLEXION CONTRACTION. (Lovett, "Treatment of Infantile Paralysis.")

such as a throat stick, and opening this slit at the back straightens the knee. By adding each day thin pieces of wood the slit is rapidly widened and the plaster made straighter without causing much discomfort to the patient (Fig. 231). Recent deformities of the knee can be corrected in a few days, and the moderately serious ones within three or four weeks as a rule. The severe and long-standing cases will require

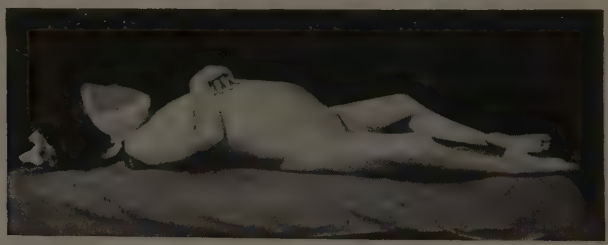

FIG. 232.—EXTENSIVE PARALYSIS OF BOTH LEGS WITH FLEXION CONTRACTION AT HIPS AND KNEES AND EXTREME DOUBLE TALIPES EQUINUS. (Lovett, "Treatment of Infantile Paralysis.")

many weeks. This method is preferable to attempting to stretch the knees by means of a splint.

In my own experience it has not been found necessary to do a cutting operation for the relief of this deformity since the method of wedging was adopted. This method is preferable to attempting to stretch the knees by means of a splint. In case of a very resistant de-

formity, which would be uncorrected by this means of stretching, division of the hamstring tendons would be required, which should be performed by the open incision rather than by subcutaneous tenotomy.

Flexion Deformity at the Hip.—This is the most serious of the deformities of the lower extremity, not easily prevented when the hip flexors are stronger than the gluteus maximus, and not generally amenable to mechanical measures such as stretching. It is frequently overlooked, and is of itself an obstacle to proper walking with braces and crutches even if it does not make walking wholly impossible.

Fig. 233.—Contraction Deformity of Left Hip Showing Position in Standing with Increased Lordosis. (Lovett, "Treatment of Infantile Paralysis.")

Operation for Hip Flexion.—In former times a very unsatisfactory transverse myotomy was the only means at our disposal for the correction of this deformity. It consisted simply in a muscular division below the anterior superior spine, often going down very deep, even to the division of the psoas tendon, and this was followed by prolonged rest in bed with hyperextension. The operation was most unsatisfactory, relapse occurred in the majority of cases, and it was a bloody and extensive operation if effectively performed.

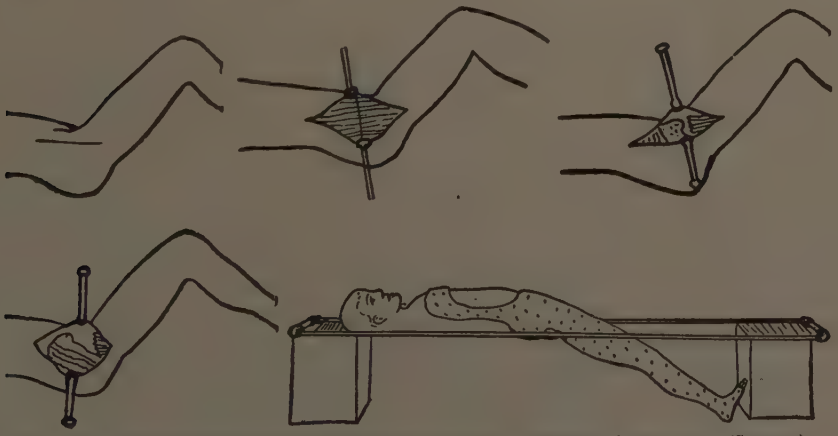

Fig. 234.—Fasciotomy for Flexion Deformity of Hip. Soutter's Operation. (Soutter.)

An effective, simple, and safe operation has been devised by Soutter,[13] which rests on an entirely different basis and which is thoroughly effi-

cient even in severe cases. It is sound in principle because it lowers the muscular origin of the tensor fasciæ femoris instead of dividing its fibers.

A longitudinal incision 2 or 3 inches long is made midway between the anterior superior spine of the ilium and the trochanter. The fascia lata is exposed and divided by a transverse incision as far back as the trochanter, reaching forward nearly to the anterior superior spine. This opens slightly, but does not give much correction. With an osteotome the periosteum from the anterior superior spine of the ilium is loosened, including the cartilaginous tip of the spine, and then along the iliac crest both inside and outside of the anterior superior spine the periosteum is loosened and stripped down, leaving the iliac crest bare. This denuding should extend as far down as the anterior inferior spine. The leg is then hyperextended, when all the tissues slip away from the ilium, leaving a large space with often a downward displacement of from 1 to 2 inches in the origin of the muscle. The wound is closed, and the patient put up in a plaster spica reaching well up on to the thorax, and kept recumbent for six weeks. It is not desirable to produce overcorrection in the initial plaster, as in serious cases the traction upon the femoral artery by the extreme hyperextended position is enough to diminish its lumen and make possible serious circulatory disturbances. The safest method is to put on a secondary plaster in a week or ten days, or in delicate children to delay the application of any plaster until ten days after the operation.

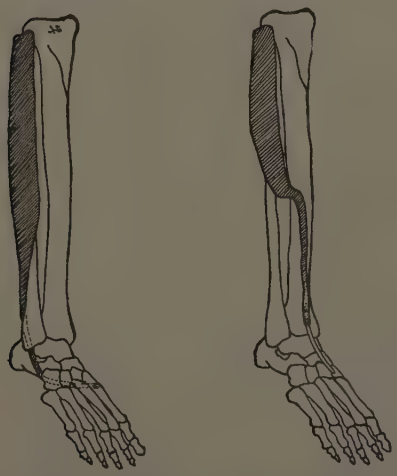

FIG. 235.—TENDON TRANSPLANTATION PERONEUS LONGUS TO INNER SIDE OF FOOT. (Lovett, "Treatment of Infantile Paralysis.")

Operations to Secure Stability of the Ankle.—This is the most frequent operative problem in infantile paralysis. Feet drawn into varus, valgus, equinus, or calcaneus by unopposed muscular pull are in most instances available for *tendon transplantation*,[14] which has held its own as an operative procedure. Simple operations have replaced complicated ones, bone insertion is better than periosteal for the transplanted tendon, and massage and exercises may be permitted in from four to eight weeks (with the foot always supported by a brace for many months afterward), when a thoroughly satisfactory implantation of the tendon has been made into the bone with a firm suture through bone, tendon, and periosteum, provided a skilled person gives such treatment. The most useful varieties of tendon transfer at the ankle are shown in Figs. 235–237.

Dropped Foot.—This deformity is a serious obstacle to walking, and

if the foot is flail it is very often unstable. When the foot is fairly stable, but merely drops, *tendon fixation* is available, although the operation is open to the objection that the anterior tendons occasionally stretch.[15]

The method consists in exposing and isolating the one or more of the paralyzed tendons whose support is desired. The tendon is drawn taut to correct the deformity—varus, valgus, equinus, or whatever it may be—and is buried in a groove in the bone located in such a way as to counteract the deformity, the tendon is scarified and sewed in place by kangaroo tendon sutures passing through the tendon and the periosteum or cartilage at the sides of the groove. The wound in the skin is closed and the foot held by plaster in the corrected position for six weeks, after which walking is allowed.

FIG. 236.—TENDON TRANSPLANTATION EXTENSOR OF GREAT TOE INSERTED WITH TARSUS. (Lovett, "Treatment of Infantile Paralysis.")

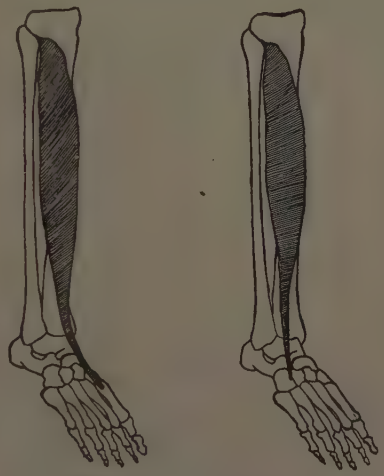

FIG. 237.—TENDON TRANSPLANTATION ANTERIOR TIBIAL TO OUTER SIDE OF FOOT. (Lovett, "Treatment of Infantile Paralysis.")

Excellent results, on the whole, are reported, and the advantage of the operation is that, as in the silk-ligament operation, dorsal flexion is allowed, but not plantar flexion. The operation may also be used in calcaneus deformity and in varus and valgus. The disadvantage is that it permanently throws out of use muscles which might improve under the favorable conditions of balance brought about by the operation, and that the anchored tendons at times slip or stretch. The operation may be used in addition to tendon transplantation. The operation as to deformities is shown in the illustrations. Its best application seems to be in foot-drop (Figs. 238–240).

In dropped foot the use of *silk ligaments* has lost ground, the silk often stretching or tearing out. For this has been substituted the use of *free fascia transplants* taken from the fascia of the thigh in place of silk, but it is too early to speak definitely of ultimate results because this application of the operation is as yet too recent.

When the foot is *unstable as well as dropped, astragalectomy*,[16] with posterior displacement of the foot, offers the best outlook if the knee and hip are able to function, but it is not good surgery to perform so serious an operation (except to remove deformity) when the leg is useless for walking, because a brace would have to be worn anyway, which brace might as well include and support the ankle. There has been a tendency in some quarters to regard astragalectomy as a cure-all for foot deformity, and many children with badly distorted feet bear witness to this tendency. It is essentially not an operation to be done in young children except for urgent reasons. The normal growth and shape of the foot are produced by several growing epiphyses in the metatarsal bones, and the balance between them produces a normal foot. The removal in early childhood of so important a component of this

FIG. 238.—TENDON OF PERONEUS LONGUS HAS BEEN FIXED IN ANTERIOR BORDER OF EXTERNAL MALLEOLUS AND TENDON OF PERONEUS BREVIS IS READY TO BE LAID IN TROUGH PREPARED FOR IT BEHIND THE MALLEOLUS. (Gallie.)

mechanism as the astragalus is followed in many instances by a serious twist in the tarsus, generally in the direction of varus, which renders the foot often a source of great trouble, the correction of which is exceedingly difficult. The operation, therefore, in my opinion should be done only for good cause, and preferably between the ages of ten and twelve years.

Arthrodesis.—With the performance of the operative measures mentioned this operation is performed very much less often. It is open to all the objections pertaining to astragalectomy and gives a stiff foot, whereas in astragalectomy a certain amount of anteroposterior motion may often be retained.

Summary of the Treatment of Deformity of the Lower Extremity.—The operative treatment of deformities of the lower extremity may be summarized as follows, the order indicating, in my opinion, their preference.

Talipes Equinus.—Stretching, tenotomy of the tendo achillis *if the anterior muscles have fair power.* Transplantation of the extensor of the great toe or other extensors into the tarsal bones, anterior artificial ligaments with or without tenotomy, tenodesis, arthrodesis.

Talipes Calcaneus.—Astragalectomy, tenodesis, arthrodesis.

FIG. 239.—ALL THE STRUCTURES HAVE BEEN REMOVED FROM THE SKELETON EXCEPT THE TIBIALIS ANTICUS MUSCLE AND TENDON, WHICH HAS BEEN BURIED IN THE TIBIA TO PREVENT FOOT-DROP. THE STITCHES ARE SHOWN. (Gallie.)

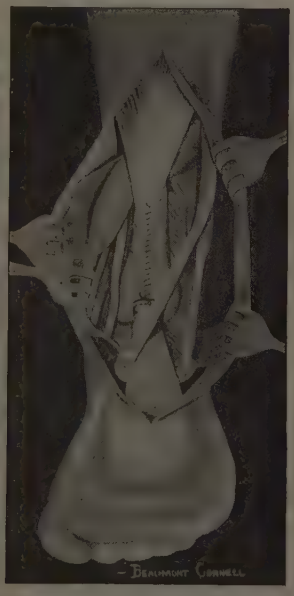

FIG. 240.—THE TENDO ACHILLIS IS FIXED IN THE POSTERIOR SURFACE OF THE TIBIA TO PREVENT CALCANEUS AND THE PERONEAL TENDONS HAVE BEEN TRANSPLANTED INTO THE OS CALCIS. (Lovett, after Gallie.)

Talipes Varus.—Transplantation of the anterior tibial when that is active to the outer third of the foot. Artificial ligament from the fibula to the cuboid, astragalectomy, tenodesis, arthrodesis.

Talipes Valgus.—Transplantation of extensor proprius hallucus or of one of the peroneals to the inner side of the foot, artificial ligaments from the tibia to the inner side of the tarsus, astragalectomy, tenodesis, or arthrodesis.

Flexed Knee.—Stretching, open division of hamstrings; rarely, osteotomy.

Knock-knee.—Supracondyloid osteotomy.

Flexed Hip.—Fasciotomy (Soutter's operation).

BONY DEFORMITY IN RICKETS[17]

A consideration of *x*-ray appearances in this disease, so little studied in its surgical aspect, shows that constant changes are to be found while the disease is active, and are located most markedly in the epiphysis and the epiphyseal end of the shaft; but they also involve the shaft. The most important of these changes are: (1) Delayed ossification and indistinctness of the epiphysis, (2) fraying out of the end of the shaft next to the epiphyseal line, (3) broad bones, and (5) areas of diminished density in the bone shadow of the shaft. Periosteal thickening and multiple fractures often occur in the acute stage of the disease.

From a study of *x*-ray plates the disease can be seen to divide itself into three stages which, on the whole, are distinct. These apparently correspond to three stages based on anatomic and pathologic data advo-

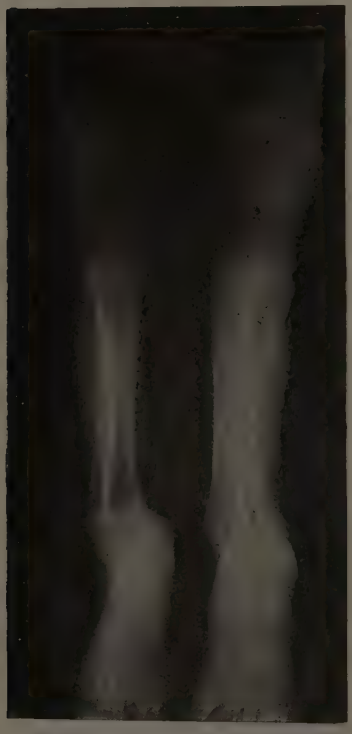

FIG. 241.—ACUTE RICKETS.
First stage: Indistinct epiphysis, periosteal thickening, fractures. (Lovett, Jour. Amer. Med. Assoc.)

FIG. 242.—KNEE IN ACUTE RICKETS SHOWING INDISTINCT EPIPHYSES AND RAGGED DIAPHYSEAL ENDS WITH BLOCKING OFF OF LOWER END OF SHAFT. (Lovett, Jour. Amer. Med. Assoc.)

cated by Guerin and Monti,[18] as the stages of swelling and rarefaction, deformity and organization, healing and reparative eburnation.

In the **first stage,** the period of onset and acute metabolic disturbance, the ends of the diaphysis become frayed out instead of clear cut, and the epiphysis casts little or no shadow, while the center of ossification is small or absent, and at times appears multiple. The whole joint is surrounded by a hazy cloud. In severer cases at this stage the epiphyseal appearances are similar, but more marked. In the diaphysis, severe general bony atrophy exists, and there is pronounced periosteal thickening, associated often with fracture of the bones, most

often in the arms. These cases of multiple fracture are very common and are often erroneously considered as osteogenesis imperfecta or "brittle bones."

In the **second stage** the shadow of the epiphysis becomes more marked. The area is ragged and irregular about the margin, and calcification is more marked at some points than others, which results in a characteristic mottled appearance. The ends of the diaphysis begin to broaden, especially on the side on which the strain is greatest, which produces a ledge or lip next to the epiphyseal line. The diaphysis in

FIG. 243.—SECOND STAGE OF RICKETS.
Epiphyses more ossified, ends of bones broadening, more marked on the side on which the strain is greater. (Lovett, Jour. Amer. Med. Assoc.)

this stage begins to give a more definite shadow. The region next to the epiphysis is streaked longitudinally, and is the area of maximum disturbance.

At the end of the diaphysis next to the epiphyseal line there often appears in the late second or early third stage a clear transverse white line, showing an increased deposit of lime in the lower end of the shaft. This is apparently not to be distinguished from the "white line" which is described as characteristic of scurvy, but which is equally characteristic of rickets.[19]

In the **third stage** the epiphysis begins to resume its normal contour

and homogeneous shadow density. Irregularities persist in the marginal outline, and there is still a little mottling in the ossification. The lipping of the diaphysis has enlarged the ends of the bone, and there is, in consequence, a discrepancy in breadth between the diameters of the diaphysis near the epiphyseal line and the epiphysis. This relative difference in size is characteristic of this disease. The clouded condition surrounding the joint in the earlier stages has gradually cleared away, and, in consequence, the bone shadows are more definite. The white line mentioned in the second stage becomes more pronounced in

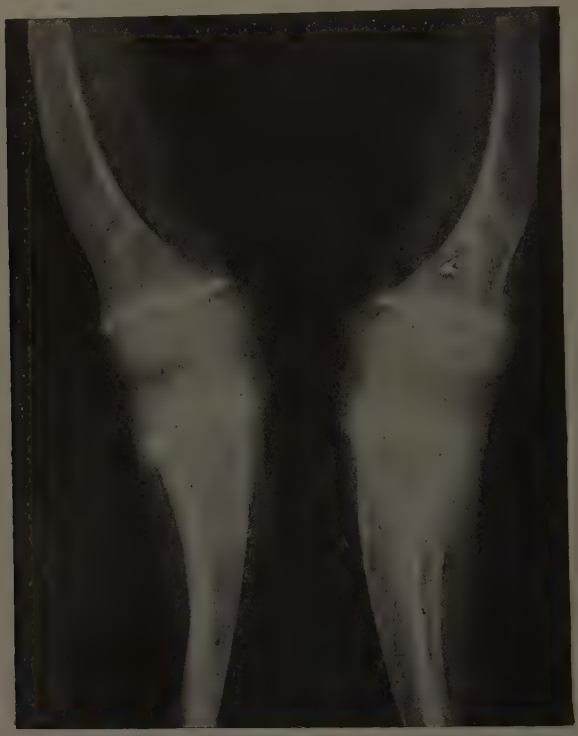

FIG. 244.—SECOND STAGE OF RICKETS, SHOWING RETURNING OSSIFICATION.
Note "white line" at ends of diaphyses described as characteristic of scurvy; chambering of lower part of femur. (Lovett, Jour. Amer. Med. Assoc.)

the third. The third stage is what may be termed the "period of convalescence."

For diagnostic purposes, therefore, the changes may be summarized as follows: The epiphyses show scanty and irregular osseous deposit, and never have a clear normal outline during the acute process. The end of the shaft is streaked, and presents an irregular line at the joint end and above it a curious transverse zone of different structure from the rest of the bone. The interior of the shaft becomes chambered and irregular, and the whole shaft casts less shadow than normal. The ends of the shaft broaden at the junction with the epiphysis, and throw

out ledges on the side when strain is to be met. A compensatory cortical thickening occurs on the concave side of curved long bones.

In rickets the thickening is endosteal in origin, and is always on the concave side of the curve, while in syphilis the thickening is periosteal or osteoperiosteal, and is very uniformly on the convex side of the curve, resulting in the lower leg in the characteristic "saber tibia."

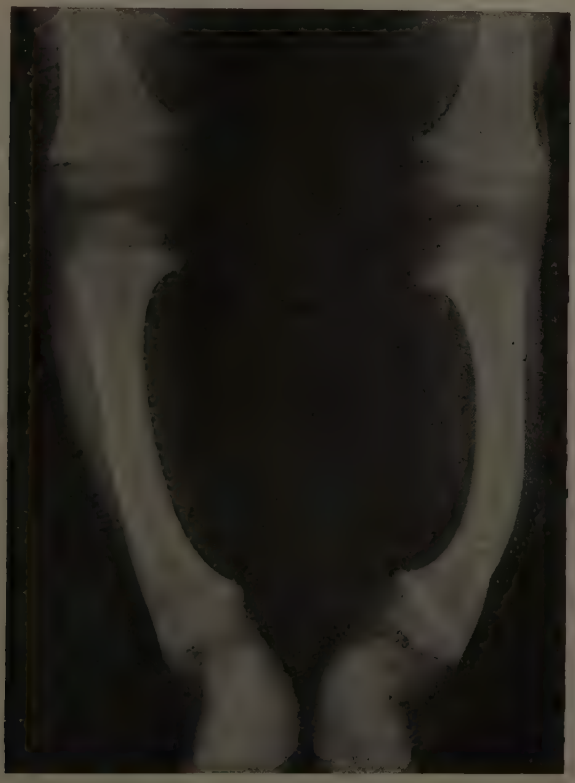

FIG. 245.—THIRD STAGE OF RICKETS.

Clear and ossified epiphyses, curved bones with compensatory thickening on concave side of curve, broadened ends of shaft at epiphyseal line, increased density of bone. (Lovett, Jour. Amer. Med. Assoc.)

This thickening in syphilis may occur on both sides, however. The epiphyses remain normal in scurvy and in osteogenesis imperfecta as well as in syphilis. This is important, as confusion in diagnosis often occurs between these three conditions. No operation should be performed on rachitic bones until late in the third stage. If it is done earlier the bones will be found soft and vascular and relapse is likely to occur.

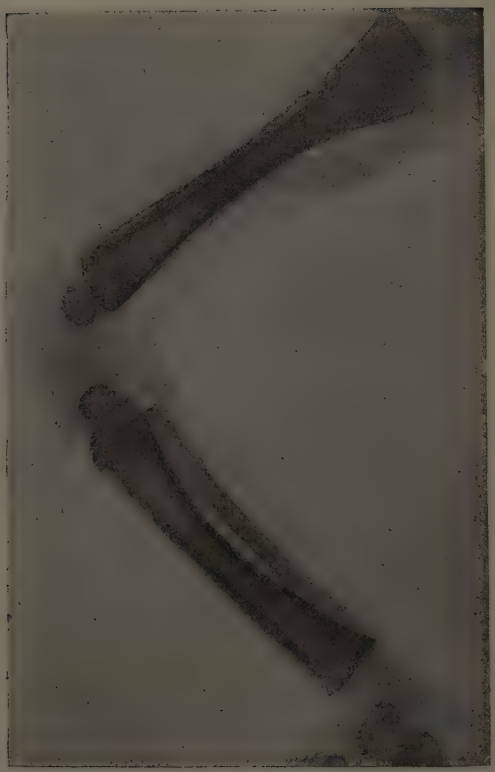

Fig. 246.—Side View of Leg Bones in Congenital Syphilis, Showing Periosteal Thickening, but Distinct Epiphyses. (After Fraenkel.)

Fig. 247.—Scurvy, Showing Bone Atrophy, "White Line," and Periosteal Disturbances in Shaft, but no Trouble in Epiphyseal Regions. (Lovett, Jour. Amer. Med. Assoc.)

FLAT-FOOT

The use of this term on an extended scale to cover most of the static disorders of the foot has led to much misapprehension, much bad treatment, and many unsatisfactory results. A more modern view of the matter must be taken.

The term "flat-foot" was originally the only one in use to describe static disorders of the feet, and was almost universally applied to them twenty-five years ago. Then came the terms "pronated foot" and "weak foot," and among the laity of late years one hears much of "broken," "dropped," and "fallen" arches, and finally there is now beginning to be used what is apparently the most correct name of all, namely "foot strain."

Real flat-foot, of course, exists, but the use of the term should be restricted to feet which are really flat and which touch the ground where the arch should be, or where the arch of the foot is really low, a matter which the most casual examination can detect. These flat feet may be rigid and resist correction, or in the non-weight-bearing position the arch may return to a certain extent, the former being rigid flat-foot and the latter flexible flat-foot. Flat feet, however, are not necessarily painful feet, but often are very serviceable.

In a research covering several years 800 trained nurses in a large hospital were observed and studied during their hospital residence.[20] The conclusion which was formulated was to the effect that the static troubles in the feet which developed among these 800 nurses of the type which would ordinarily be described as "flat-foot," "pronated foot," "weak foot," etc., could not be traced to any particular type or structure of foot. The figures as to the durability of these feet showed that the foot with the high arch, which touched only at the front and back and not on the outer border at all, was slightly less enduring than any other form of foot—in other words, that a high arch was more likely to give trouble than a low one. In short, a careful examination of the foot did not enable one to predict at all which feet would be enduring under strain.

The inevitable conclusion from this research, which has been wholly borne out by my experience in private practice, and in the medical corps of the United States Army, is that the pain and disability cannot be attributed to the lowering of the arch, but to muscular strain, not necessarily attended by any perceptible change in the structure of the feet, and that the foot with a high arch is notably subject to foot strain. In foot strain it is probable that ligaments also become irritated by the failure of fatigued and overstrained muscles to reinforce them as they should do normally, and thus that ligaments also serve as a source of pain and tenderness. Moreover, some degree of synovitis may arise in the tarsal joints, as, for instance, in the astragaloscaphoid joint, the under surface of which is frequently thick and tender in cases of foot strain.

The boot must be regarded as the most important contributing factor to foot strain, for the shape of the boot is never the shape of the normal

adult human foot. The back part is well enough, but the front practically always compresses the forefoot, and this does much harm in narrowing and weakening the base of support which the forefoot should afford; yet this is not the whole evil, which it is usually supposed to be. A serious difficulty lies in the curve of the sole of the boot, because the shape and curve of the sole of the boot assumes that all feet are alike and that all feet possess rather a low arch; consequently a fair proportion of the community are wearing shoes which impede the muscular action of the foot, but do not afford a prop in the arch to compensate for it. In other words, the arch of the sole of the boot is often not so high as the arch of the foot. In most cases this does no harm because the individual is vigorous enough to overcome the handicap; but it is a bid for foot strain in those less well equipped, and accounts for many if not most of the cases of so-called flat-foot when there is no perceptible flat-foot.

Real flat-foot, if painful, must be treated; if not painful, it should be let alone. If it is to be treated, rigid flat-foot is to be reduced under ether, or in extreme cases a wedge of bone must be taken out of the inner side of the arch. Painful flexible flat-foot may be treated by supports.

The question of interest, however, comes in the treatment of flat-foot which is not flat-foot, which should be spoken of as foot strain. What has been said here would show that in formulating such treatment one should attach little importance to whether or not the foot was pronated. But one should attempt most carefully to study the conditions which produced strain, with a view of relieving it, and one should be especially on the lookout for an unduly high arch. The shape of the sole of the boot should be compared with the curve of the sole of the foot, and it will often be found that the leather of the sole inside of the boot under the arch of the foot has never even been defaced by the pressure of the foot.

If one considers the problem from this point of view, we are dealing with tired and overstrained muscles, probably irritated ligaments and disturbed circulation in the foot, attended by no especial lowering of the arch, but perhaps with a little rolling of the foot on its inner side. It would seem reasonable that rest should be furnished to the overstrained muscles by supporting the under side of the foot most at its inner side. This support would best be furnished by a boot the sole of which was of a proper curve to support the arch of the foot, but it is practically impossible to get such boots made, and one finds it far easier to modify a ready-made boot than to secure one made to order fulfilling the proper requirements.

It is possible in the slighter cases, when an obviously bad boot has been worn, to remedy the trouble by the use of one of the good ready-made boots with as high an arch as may be obtainable; but more often it is necessary to raise the arch higher than this, which is readily done by splitting the leather forming the shank, removing the small piece of iron or stiffening which is already there in most boots, and replacing

it by a piece of steel with a higher and longer curve, which can be easily made. For temporary support, the well-known strapping by adhesive plaster is of use. In shoes with a stiff enough shank, pads of felt cut to fit the arch of the foot may be of use in some of the milder cases.

The moderate and severe cases will in most instances be more quickly relieved by a proper fitting metal support than by any other means. The object of this metal support is not to force the arch of the foot back into place, but simply to do what the boot does not do in supporting the strained and irritated arch; consequently heavy plates with flanges are not necessary. When they are put in the boots they should be comfortable, and if not they should be lowered until they are. Such strained feet, as a rule, are at least slightly swelled and thick in the arch, and as such swelling subsides, as it usually begins to do in two or three days, the plates may have to be raised slightly, after which they are tempered and nickel plated or covered with leather. They are worn as long as may be necessary, and the majority of patients sooner or later are able to dispense with their use without a return of symptoms, especially if they wear a boot which supports them better in the arch. If they have to wear them permanently it is because the foot has been so damaged or is intrinsically so weak that it must be supported, and in our inability to get properly constructed boots made we have to resort to the clumsy addition of a metal plate.

Ill-fitting plates do harm by contusing the soft parts of the foot, and sometimes by straining it by holding it in an improper position. The plates as sold in shoe stores have too short a curve, and, as a rule, are sold by persons ignorant of the first principles of plate requirements. They are often so soft that they bend under use, and nothing is more irritating than a rigid support which does not support.

There is a good deal of doubt as to the benefit of exercises as a treatment for foot strain in the acute stages. Many cases are often made worse by them, as by the use of the flexible shoes so frequently prescribed. Such shoes may have their use as a method of muscular exercise when the acute irritation is subsiding, but not often in the acute stage. Attempts at the gradual discontinuance of the plate should be made after a few weeks or months, and if it fails, then a series of exercises should be prescribed, after which a further attempt should be made.

CLUB-FOOT

An operation has been devised which is less mutilating and more effective than the other operation for moderate and severe congenital club-foot. This operation was devised by Frank R. Ober and has been done at the Children's Hospital and elsewhere on rather a large scale, with most satisfactory ultimate results. The operation is as follows:

Ober's Operation for the Relief of Club-foot, Equino Varus.[21]—An incision is made half-way between the tibia and tendo achillis, beginning $1\frac{1}{2}$ inches above the level of the internal malleolus, extending down, swinging around and below the malleolus, and ending in a sharp

upward curve over the anterior navicular region. The incision is carried through all the tissues to the deep layer of fascia. The skin-flap is dissected off the fascia anteriorly, giving a wide exposure of the medial aspect of the tarsal joint. A semilunar incision is made $\frac{3}{4}$ inch above the malleolus, beginning at the edge of the posterior tibial tendon and extending forward and downward through the anterior portion of the deltoid ligament to the lower border of the navicular. Incision on the tibia goes through the deep fascia and periosteum to the bone. By means of an osteotome or periosteal elevator the above structures are pushed off the internal mallelous, including in the flap the vertical portion of the deltoid ligament. If the posterior tibial tendon is very short it should be split and divided by a zigzag incision in order that it may be lengthened before the wound is closed.

The flap thus begun is retracted very strongly so that the tip of the sustentaculum tali is exposed. By means of a tenotome the periosteum is incised close to the attached ligaments on the anterior and posterior borders of the sustentaculum. With a blunt dissector the periosteum with ligaments is dissected off the inferior surface of the sustentaculum and the medial surface of the calcaneus. The anterior portion of the inferior calcaneonavicular ligament is removed from the navicular bone in a similar manner.

The anterior tarsal ligament is usually adherent to the articular surface and the neck of the astragalus, and must be cleared before it is possible to secure dorsal flexion.

The plantar fascia is next tenotomized. By means of a club-foot wedge under the cuboid the foot is forcibly abducted. Following this maneuver the foot is forcibly abducted, everted, and dorsally flexed until as much overcorrection as possible is secured. The tendo achillis should now be divided and more overcorrection obtained by manipulation.

The bone-ligament-flap is sutured to the ligament over the medial aspect of the navicular in such a way that the flap will become attached lower down to the malleolus. The subcutaneous fat and fascia are sutured with interrupted chromic catgut. The skin is united with interrupted No. 12 silk. This size silk is used because there is considerable tension on the skin, and other forms of suture material tend to slough out.

A plaster cast is applied from the toes to the groin, with the foot in very slight overcorrection and the knee flexed in order to prevent inward rotation of the tibia. A window is made over the wound in order to relieve pressure on the suture line and also to allow the tarsal joint to bulge inward. As the foot is lengthened in this operation there is considerable disturbance of circulation if the foot is put up in marked overcorrection. After twelve to fourteen days the plaster is removed, the stitches in the skin taken out, and a new plaster cast similar to the first is applied, but the foot should be put up in full overcorrection. Plaster casts are worn from four to six months, followed by a suitable club-foot brace for six or eight more months.

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PROPERTY OF SURGICAL OFFICE
NOT TO BE REMOVED

CHAPTER XXIII

MILITARY ORTHOPEDIC SURGERY

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INTRODUCTORY

The first difficulty with which the authors of this article are faced is that of definition or delimitation. Orthopedic surgery in the ordinary sense is concerned with the prevention and cure of deformities, and in this sense deals with maldevelopment or disease affecting the bones, joints, and muscles of the spine and limbs.

In military orthopedic surgery we ought to be able to exclude conditions of faulty development or of long-standing deformity, *e. g.*, spinal curvature or club-foot.

As a matter of actual practice, however, this is not the case, because in times of rapid enlistment and mobilization a great many men are accepted with various deformities, of which the commonest are flat-feet, claw-feet, knock-knees, and some degree of scoliosis. It is not necessary to describe the treatment of such conditions, because they are fully dealt with elsewhere in this system. But two things should be said.

The first is that great care should be exercised in the training of recruits and in fitting them with boots. All those who have been used to a sedentary life should have special graduated marching exercise, so as to bring the feet into good condition. Those who, in spite of this, complain of tired and aching feet should be provided with boots with the inner edges of the heel and sole slightly raised, so as to relieve the arches of the foot of undue strain.

The second is that in case of well-marked deformity it is far better to reject the man from any fighting branch of the service than to accept him in such, and then to have him for a great part of his military career as a patient in hospital.

As a matter of actual experience the most difficult point in the limitation of military orthopedics has been in the case of severe gunshot fractures and injuries to nerves. Both of these lesions lead so inevitably to deformity unless properly treated from the outset, and both require from the outset and for a long period afterward such careful nursing back to proper function, that it was found advisable to include all these cases in the scope of military orthopedic surgery. Then, again, there are all sorts of neurotic conditions involving deformity or the loss of function of the limbs. Where these conditions are purely functional they are no doubt better segregated with neu-

rasthenic cases, but where a large functional element is added to a definite injury then for a long time the patient will have to be in hospital, and it has been necessary to deal with such in special departments of the orthopedic centers.

If, therefore, the liability to deformity be taken as the criterion of those gunshot injuries which should be classed as "orthopedic," we have the following list:

Injuries of the limbs: Fractures of the long bones.* Injuries to the joints. Adhesions and contractures of muscles and tendons. Functional paralysis or deformity associated with other injuries of the limbs.

It has been contended that such an inclusive list trends far into the domain of general surgery and far outsteps the limits of "orthopedic" surgery, which is concerned with the deformities of the growing child. But, after all, such contention is merely one of etymology, and the practical fact remains that it is just as essential to segregate and specialize in the treatment of severe limb injuries, as it is those of the head, eye, thorax, or abdomen.

GENERAL ADMINISTRATIVE PRINCIPLES

To those who have been concerned in the problem of orthopedic surgery for many years it would seem that, as far as scientific principles are concerned, little or nothing really new has been discovered during the great war. But, on the other hand, it is equally evident that in no branch of military medicine or surgery have such great improvements been effected as in the treatment of injuries of the bones and joints. This improvement has been due to the recognition and adoption of certain administrative principles which we may tabulate as follows, and then proceed to discuss them *seriatim:*

Prophylactic treatment of deformities. Continuity of treatment. Segregation of limb cases. Organization of team work. Standardization of apparatus. Proper relations between authority and initiative.

ON THE PREVENTION OF DEFORMITY

If there was any real antagonism between the treatment of the infected wounds of the soft parts and that of the bone and joints there would be some excuse for the neglect of subsequent deformity. But as a matter of experience, it has been amply demonstrated that immobilization in a correct position with proper movements begun at the right period can always be carried out in such a way as to allow proper treatment of the wound. Therefore it must be made a matter of the first importance in practice and in instruction that such correct fixation and movement should be instituted from the earliest possible moment. It is only necessary to study the results of the neglect of this rule to appreciate its importance. Thus we find arms fixed to the side, elbows or knees fixed in flexion or extension, forearms fixed in pronation, hands in palmar flexion, legs shortened by adduction, and feet crippled by

* Limitations of space have obliged us to confine ourselves in this article to fractures of the femur, as regards early treatment.

plantar flexion of the sole or of the great toe. These are, of course, very elementary things, but they are none the less of fundamental importance. Then there are other matters where the justification for radical primary treatment should always be viewed in the light of after-results. Such are the removal of the fragments from a comminuted fracture of the shaft of a long bone and the wide excision of an injured joint.

It may appear to an operator at a C. C. S. that he gets much better immediate results from either of these than from more conservative procedures. But if a year later he sees cases treated by these methods he will be impressed with the fact that his zeal has produced an ununited fracture in the one case and a flail joint in the other.

In the same way many a surgeon has plated septic fractures just because, for the moment, the distorted bone was thereby held in good position, ignoring the fact that such treatment ultimately involves an extensive necrosis of bone or a loss of the limb. Thus, from the earliest stage of the treatment of wounded limbs, correct position, properly timed movements, and correct surgical intervention, as judged by late results, must be adopted.

CONTINUITY OF TREATMENT

One of the greatest difficulties of the administration in the late war has been to secure intelligent continuity of treatment for cases whose recovery occupied many months. The best example of this is seen in the fractures of the femur. When these cases were first treated for a few weeks in France and then sent for a few weeks to a General Hospital in England, and finally for many months to an auxiliary hospital, the results were deplorable. And this in spite of the fact that at each stage there may have been excellent surgeons at work. When the British cases of fractured femur were kept in France until consolidation occurred a great improvement in results was noted. But this plan was liable to be upset by the exigencies of war, and it was often a great drawback to keep men for months where they were liable to be bombed by air raids. The best results of all were obtained when the cases were sent to England within ten days of being wounded and then kept in special hospitals until their convalescence.

SEGREGATION

It is absolutely essential in order to obtain the best results and also for the best utilization of personnel and apparatus that all limb cases liable to serious deformity should be brought together into special hospitals or into special sections of large general hospitals. It was this principle which led to the founding of the Military Orthopedic Centers in 1916 in England.

This innovation was viewed with doubt by the administrative authorities and even with hostility by a certain number of surgeons. But in spite of these influences the experiment proved so successful that the movement rapidly grew in magnitude and importance, and the

authorities sanctioned the formation of several large centers in every military command, while the allegiance of the general surgeons was secured by naming them "Special Military Surgical Centers" and calling into their service all surgeons, old and young, who had special knowledge and experience of surgery of the limbs or who were willing to acquire this knowledge.

TEAM WORK

Segregation of the cases is merely a preliminary necessity for team work. However much a speciality such as orthopedics is practised and developed, the men with wide experience and formed judgment will always remain comparatively few. Such men's services must be utilized with the utmost economy as the directors of special hospitals. Then at each such hospital several teams of operators, assistants, and dressers must be trained to work together, while nurses and orderlies are taught the special technic to be employed. Attached to several operating teams will be specialists, such as the director of massage, electricity, hydrotherapy, physical exercises, psychotherapy, and curative workshops.

Thus a complete team such as would administer a 1000-bed unit would consist of:

Surgical director, 1. Operating surgeons, 4. Assistant surgeons, 8. Physiotherapy (electricity, massage), 1. Hydrotherapy and radiant heat, 1. Gymnasium, 1.* Curative workshops, 1.* Radiographer, 1. Pathologist, 1. This list does not include administrative officers, such as Commandant, Registrar, Quartermaster, neither does it allow for special anesthetists; the anesthetics being given by one of the two assistant surgeons attached to each operating surgeon. In many centers, moreover, the physiotherapy has been divided up under two officers, one of whom superintends the massage and the other the electric treatment. But, on the whole, we think that the above represents the best arrangement, because it is most important for after-treatment to be as much unified as possible, and that it is an unmixed evil if its several departments be made independent of one another. In fact, if a really suitable officer can be found to superintend the massage, electric treatment, hydrotherapy, and gymnasium, with competent subordinates in each section, this is undoubtedly the best arrangement of all.

The keynote to good orthopedic surgery is the rapid restoration of function. The surgeon must decide upon operative measures and carry them out; he also decides upon questions of splinting or mobilization. The restoring of the muscles, nerves, and joints to actual use is for the after-treatment department, aided, of course, in special cases by the psychotherapist. The value of this after-treatment will depend upon three things: the care with which it is carried out, the intelligent adaptation of various methods and doses of treatment to each case, and to the close co-operation between the surgical team, on the one hand, and the director of the after-treatment on the other.

* These two need not be medical men.

THE STANDARDIZATION OF APPARATUS

No one who has not seen the difficulties, both in France and in England, due to the multiplication of different types of splints can realize the magnitude of these difficulties. Some surgeons appear to believe that the ideal condition of administration would provide every pattern of splint for every unit at a moment's notice and be ready to have new patterns made to order when required. But this means chaos. In the first place, it is a practical impossibility to provide hundreds of different patterns, each in large bulk, and any such attempt would be wasteful in the extreme; though the waste of labor, material, and transport is the least evil of the system. The fundamental principle which ought to guide this matter is a frank recognition of the fact that teams of surgeons, orderlies, and nurses can only become experts in the application of very few splints, and that when a large number of wounded have to be dealt with, simplicity is essential to efficiency.

This fact was quickly recognized by the Directors of the American Orthopedic Units who came to France, and they at once embodied their views in the form of a pamphlet on the "Standardization of Splints." All officers, orderlies, and nurses were trained in the use of the splints selected.

These rules are especially important when as usually happens every wounded man has to be passed through the hands of at least three sets of surgical teams, namely, those at the C. C. S., those at the Base Hospital, and those at the Special Orthopedic Hospital.

The necessity for keeping to a few standard patterns of splints applies chiefly to work done at the C. C. S. and at the Base Hospitals. If such a plan were followed it would be found that in addition to a certain stock of splinting material—*e. g.*, Gooche's kettle-holder splinting, straight angled, and posterior splints for the slighter cases—there would only be required the following:

1. One general splint for fractures of lower limb: Thomas' straight knee splint in three sizes.

2. One general splint for fracture of the upper limb: Thomas' straight splint in three sizes.

3. One splint for fractures of the upper limb with bent elbow. One of the various patterns of bent wire arm splints, *e. g.*, Thomas' for right and left arm.

4. One frame or adaptation of the standard stretcher for fractured spine or hips, with wounds of the buttock.

5. Foot-pieces for attachment to the leg splints.

At the Special Orthopedic Hospitals, where the cases are to receive their final and main orthopedic treatment, the provision of apparatus must be under the control of the Surgical Director, who will, of course, have at his disposal not only all standard splints which he may deem necessary but also mechanics and shops, where special appliances can be made to order.

PROPER RELATION BETWEEN AUTHORITY AND INITIATIVE

Military medical work necessarily involves a certain conflict between authority, on the one hand, and individual initiative on the other. No man can be allowed to be a free lance. But, on the other hand, no bar must be placed on new ideas. In order to reconcile these conflicting propositions it is absolutely necessary to have a council of consulting surgeons who should have authority to lay down rules as to surgical procedure. The consultants see all sides of the work, both early casualties and late results, and any reasonable medical officer should be willing to be guided by these rules.

There should also be a surgical censorship of publications. Surgeons have not only plated septic fractures, but have in perfectly good faith published cases without knowing anything about end-results, and so have encouraged others to follow a mistaken lead. Any departure from the rules laid down by the Consultants' Council should only be carried out after consultation, and then in all important matters proper provision should be made for following up the cases to see what are the end-results, before any publication of the method is made. This is a matter in which progress will be much more sure because it is slow.

GENERAL TREATMENT OF WOUNDED LIMBS

Wounds of the Soft Parts.—Infection.—Although the treatment of the early wounds of the soft parts does not properly belong to the domain of special orthopedic surgery, yet it cannot be too strongly insisted that the proper early treatment of the wound is essential to rapid and successful late treatment of the deeper structures. The ideal to be aimed at is to render the wound aseptic and to obtain primary or, at any rate, rapid healing before sepsis has had time to become deeply implanted in the tissues, and also in order to avoid the formation of great masses of dense scar tissue in the intervals between the muscles, tendons, nerves, bones, and joints. In fact, it may be said without fear of contradiction that sepsis with its resulting inflammation and deep scar tissue are the two greatest enemies with which we have to deal in attempting to restore the function of the wounded limb. Late reconstructive operations can never be undertaken with any chance of success in the presence of latent sepsis. It is often stated that such an operation should be postponed for several months after the closure of the wound. But this does not imply by any means that the mere waiting for a certain period will rid the tissues of septic organisms once these have been long established in their depths. In the case of bony tissues, indeed, it may be fairly doubted whether the lapse of years is sufficient to sterilize the tissues. In operating upon ununited fractures, for example, we have frequently at a preliminary operation recovered active streptococci or Bacillus coli communis at periods of one or even two years after the original wound.

There are two kinds of tissues in which these septic organisms appear to be able to live dormant for an indefinite period, these tissues being

bone, on the one hand, and scar tissue on the other. Therefore, we repeat, it is a matter of the utmost importance for all seriously wounded limbs to have the soft parts treated as thoroughly as possible at an early period. Elsewhere in the present series of articles the actual details of early wound sterilization, excision of devitalized tissues (débridement) are fully described, together with the technic of the Carrel-Dakin procedure. As a contrast to this happy state of things it would be easy to bring forward multitudes of cases in which chronic sepsis has continued for months or years. In these cases the double hostile influence of latent sepsis and dense scar tissue have rendered reconstructive operations almost hopeless.

But in addition to the early sterilization of wounds making reconstructive surgery possible, there is another reason why early healing of the soft parts is especially important in orthopedic surgery. This is in order to enable splint and postural treatment to be carried out without restriction and to be alternated with a proper dose of movements with exercise. The loss of function in a limb which it is our ultimate object to cure is always grave in proportion not only to the destruction of tissues but also to the length of time during which the limb has remained disused.

GENERAL PRINCIPLES OF IMMOBILIZATION OF LIMBS

For all serious wounds and especially those involving the bones and joints some form of immobilization is required both for transport and treatment.

It would serve no useful purpose if we attempted to decide or review all the many devices which have been introduced to serve this purpose. We will simply confine ourselves to a discussion of certain general principles. These may be grouped as follows:

1. The importance of correct posture. 2. The essential character of splints. 3. The rôle of plastic splints and of plaster of Paris. 4. The factor of time and the relation to movements.

1. **The Importance of Correct Posture.**—We imagine that no one would dispute that there is a good and a bad posture in which to fix every wounded limb, but the importance of this question has been lost sight of by many surgeons owing to the facts that the injuries of civil life recover so comparatively quickly and also that the latter are frequently lost sight of, so that after-treatment and end-results do not impress themselves on the mind. Another idea which encourages us to be casual in this respect is the fallacy that if a limb is made comfortable, then it is being well treated. Thus a patient with an injury of the shoulder (Figs. 248, 249) has his arm strapped to the side, or one with a broken leg lies in bed with his foot unsupported. In each case the method is easy for the surgeon and comfortable for the time being for the patient. But, clearly, such methods will lead to discredit and to disablement, to correct which much more pain will be required than if proper posture had been adopted at the outset. There is a best position for every limb, and it should be our aim to secure this position

from the outset and to preserve it throughout immobilization, so that when the damaged structure has been healed function may be restored as rapidly as possible. The details of what this best position is for each

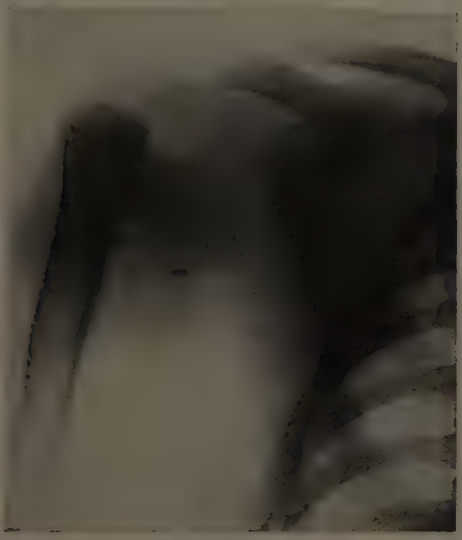


FIG. 248.—FRACTURE OF THE NECK OF HUMERUS UNREDUCED AS ARM LIES AT THE SIDE. (McMurray's case.)

joint are given in the section dealing with Ankylosis of Joints. But it may be well to point out in this connection that actual injury of the joint or likelihood of ankylosis are not the only reasons for adopting this

FIG. 249.—SAME CASE AS FIG. 248, SHOWING REDUCTION OF FRACTURE BY ABDUCTION. (McMurray's case.)

position. The other great factor which demands it is the liability of certain muscle groups to actual or functional paralysis, and also the relation of gravity to the movements of the limbs. Thus in the upper limb the abductors of the shoulder—the deltoid group and the extensors

of the hand and fingers—are those liable to loss of function if they are kept constantly extended, and also the weight of the arm in one case and the drop of the prone hand in the other will encourage this extension. Therefore the arm must always be kept abducted and the hand supinated, with the wrist dorsiflexed. Similarly, in the leg, the dorsiflexors of the foot are much weaker than the plantar flexors, and they are kept stretched by the action of gravity on the dropped foot if this posture is not sedulously corrected.

2. **The Essential Character of Splints.**—We have already insisted upon the necessity of standardizing the splints used in the early phases of treatment. In these early stages it is necessary that the splint should be—

(*a*) Simple in construction and application. (*b*) Of wide applicability, so that one or two patterns will serve the requirements of each limb. (*c*) Adapted for transport. (*d*) Adapted for axial extension. (*e*) Capable of maintaining immobility without interfering with the changing of dressings. All these essentials have been proved, by five years of war experience, to belong to the metal splints designed by Hugh Owen Thomas, and we are quite confident that neither in our own nor in that of any of our allies or enemies' armies have any other appliances been used which have approached them in simplicity or efficiency. As we shall indicate in a later section, there are many modifications of method applicable when using these splints and there are many other splints of value under special circumstances.

3. **The Rôle of Plaster of Paris and of Plastic Splints.**—Plaster of Paris used extensively for immobilization of wounded limbs may be a blessing or a curse, according to the judgment which guides its use. Certainly in early periods of wounds its dangers far outweigh its advantages, but later on it comes to have a very useful rôle, which ought to be fairly well defined. It certainly carries out absolute immobilization more effectively than any other method of splinting, but it does this at the serious cost of imprisoned muscles, tendons, and joints, which tend to become adherent and atrophic. Therefore *it should never be used if a similar object can be attained by other means.*

There is a certain type of irritable wound associated with a bone lesion, usually an ununited fracture, which will heal under plaster (which is provided with a window) better than under any other means. Again, in the gradual alteration of a faulty angle of a joint, plaster is of great service in maintaining each stage before a further correction is made. In the fixation of a limb after the operation of bone-grafting plaster is more efficient than any other method. For almost all other purposes for which plaster dressings are commonly used molded plastic splints, which can be removed for daily massage and movements, are much more satisfactory. The more elaborate types of these are too well known to require description; they may be made of celluloid, leather, or felt impregnated with shellac or other material.

4. **The Factor of Time and the Relation to Movements.**—The time which an injury takes to heal and the period of life during which

splinting is carried out are factors of great importance in deciding the relative importance of immobilization and movements. Thus the fractured femur of a child, whether it be the result of an accident or of an osteotomy, can be put up in plaster for six or eight weeks and nature will rapidly restore the full mobility to the joints. But it is far otherwise with the septic injuries of adults resulting from gunshot wounds. Very long periods are often required for consolidation of bones, deep sepsis will tie the muscles and tendons together, and in adult life stiff joints are very slowly or not at all recovered from by expectant methods. Therefore in putting up any war wound, however perfect the immobilization, this should be so arranged as to allow of massage and movements at an early date. At an early period of the war it was very common for fractured thighs to be kept rigidly fixed with a straight knee for twelve months, with the most disastrous results. We must consider it as much our duty to preserve the mobility of the knee as the integrity of the femur. This point will be referred to later.

FRACTURES OF THE FEMUR

For many years one of us (R. J.) has been accustomed to treat fractures of the femur by means of Thomas' splints and abduction frame. Soon after the outbreak of the war in response to many requests for guidance in this matter the following description of the application of these appliances to gunshot fractures was written. Since that time a vast experience has confirmed the idea of their value and has also given rise to modifications and additions which will be considered in their place.

Fractures of the Hip and Upper Thigh.—Fractures through the hip-joint and those just below the trochanter are best treated by a modification of the Thomas splint, which I have described as an "abduction frame" (Fig. 250). It is a splint upon which the patient lies and can be carried; extension is easily applied, maintained, and need not be relaxed for any purpose. The patient is placed upon this splint, and any displacement should be overcome by immediate extension in the abducted plane. The limb should be rotated slightly inward until the foot is at right angles to the table and should be fixed in this position on the frame. It will be seen by the illustration that both limbs are controlled and that extension is secured by strapping on the injured limb with counter-extension by means of a smooth leather groin strap on the opposite side of the pelvis. This groin strap *should not be slackened by the nurse under any pretext*, but in order to avoid pressure sores she *should be instructed to alter the area of skin subjected to it* over the adductor muscles by *moving it to and fro*. This method of "fixed extension" in abduction secures the lower limb in relation to the pelvis in a manner which can never be satisfactorily achieved by weight and pulley, where reliance is placed on the weight of the body for counter-extension. It is by reflex nervous impulses, induced by changes of tension in the muscle, that muscular spasm is produced. A patient lying in bed with a fractured femur—high up or lower in the shaft—cannot avoid constantly

changing the state of tension of the muscles of his thigh if a weight and pulley are attached to his limb. The counterpoise is the weight of his body. Every time he tries to shift the position of his shoulders by digging his elbows into the bed he alters the tension of his muscles, calling forth a reflex spasm. When he falls asleep and his muscles relax; when he moves in his sleep; when he is lifted upon a bed-pan or moved slightly by the nurses to have his bed put straight, there is apt to recur this reflex contraction due to sudden change in tension.

One of the objections to the old abduction frame was the difficulty of transport. The abducted limb proved difficult both on the boat and in the train. To obviate this the splint is now made so that the patient may be put up for transport with both limbs parallel. As soon as the patient arrives at hospital the limb is abducted without disturbing him in any other way.

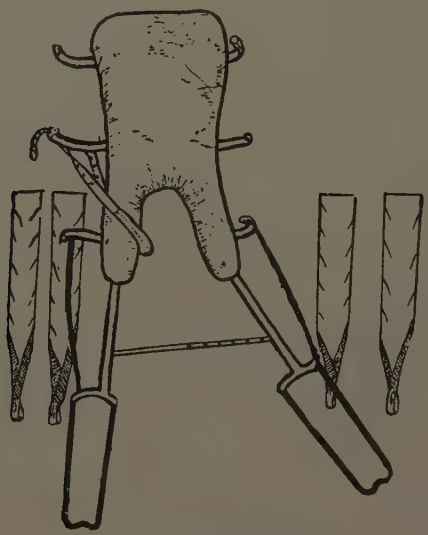


Fig. 250.—Abduction Frame.

The patient who lies on an "abduction frame" can be lifted and moved without pain, without disturbing the fracture or relaxing the extension, and the dressing can be changed without interfering with the mechanism of fixation. If the wound is through the buttock and the discharge takes place there, the splint can be modified. The abduction frame can be applied in a few minutes.

Abduction Frame.—*Measurements Required.*—Nipple to external malleolus.

Splint Measurement.—From chest band to ankle grip, 4 inches short of above measurement.

Application.—A strip of adhesive plaster, to which a strong loop has been sewn at one end, is applied to each side of each leg. The adhesive plasters should reach from as near the lesion as possible to

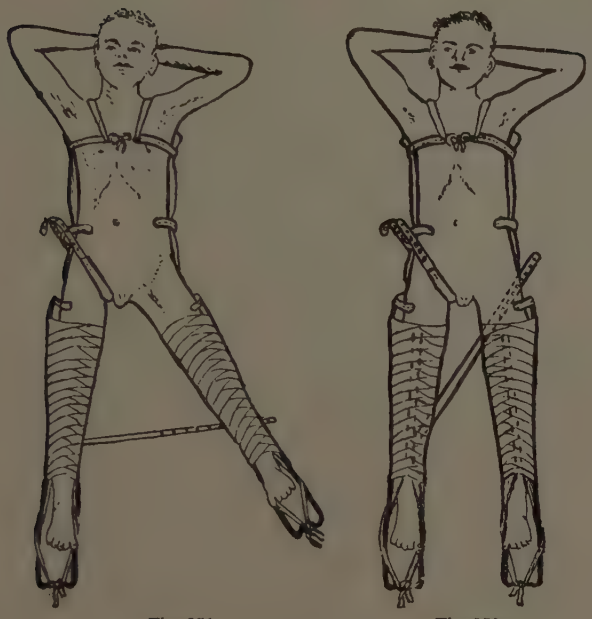


Fig. 251. Fig. 252.

FIGS. 251, 252.—SPECIAL MODEL OF ABDUCTION FRAME IN WHICH ABDUCTED LIMB CAN BE BROUGHT PARALLEL TO ITS FELLOW DURING TRANSPORT.
Fig. 251.—Leg abducted. Fig. 252.—Legs parallel.

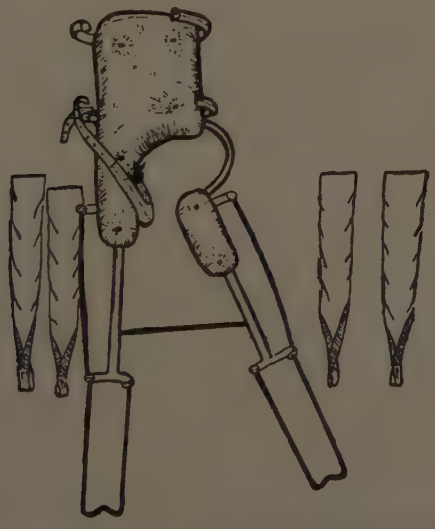


FIG. 253.—MODIFIED ABDUCTION FRAME FOR PELVIC WOUND; ONLY TO BE USED WHILE WOUND DISCHARGES.

the malleoli—the loops lying at each side of the heel. Bandage these on firmly. The patient now lies on the splint, but before bandaging down the knees lay the body of the groin strap along the gluteal fold of the

sound limb, securing it by means of its perforated ends to the pegs on the splint wing. Next apply the traction required to the injured limb, maintaining it by tying the external loops to the end of the splint by means of a bandage which has previously been passed through the loops. The groin strap remains stationary. Further traction of the limb is obtained by means of this extension. The sound limb should have very slight traction applied to avoid pelvic tilting.

Nursing Hints for a Patient on an Abduction Frame.—The patient should never be turned for any purpose, as the spine and limbs will sag laterally. Place a block underneath the bar between the ankles to avoid pressure to heels, increasing height of block when necessary to insert a flat bed-pan beneath the splint. Also in this raised position all necessary washing of the buttocks can be done. The patient is never taken from the splint nor are the bandages removed for this purpose, but only the exposed skin is washed. The feet should be supported at right angles, and protected from the weight of the bed-clothes. Remove the groin strap for five minutes four-hourly during the first twenty-four hours; twice daily is usually sufficient afterward. Rub area with spirit and powder during these intervals, replacing strap in same hole as before, but, as much as possible, over a different adductor skin surface.

Upper Middle and Lower Thigh.—For all other fractures of the thigh the Thomas bed splint is incomparably the simplest and best. I have often fixed a fractured thigh in this splint, and sent the patient home in a cab. By reason of its construction it automatically secures a correct alinement, as any surgeon with a mechanical mind can see if he examines the illustrations (Figs. 254, 255).

I am in the habit of using this splint for the treatment of all fractures of the middle and lower third of the thigh, fractures through the knee-joint, and fractures through the upper and upper-middle portion of the leg.

The application of the Thomas bed splint is quite easy. Strapping or adhesive plaster is applied in the usual way to the sides of the limb. At the lower end of the extension strapping there is a loop of webbing to which is attached a length of strong bandage. The ring of the splint is passed over the foot and up to the groin till it is firmly against the tuber ischii. The extensions are then pulled tight, the ends turned round each side bar and tied together over the bottom end of the splint, which should project 6 or 8 inches beyond the end of the foot. Care must be taken to avoid internal or external rotation of the limb, the foot being kept at right angles. A couple of transverse bandage slings suspend the limb from the side bars of the knee splint. A straight splint is placed behind the suspensory bandages of the thigh and knee. On the front of the thigh another sheet-iron splint is applied, and the femur is thus kept rigid. The alinement from the hip-joint to the ankle is perfect, being dependent on a straight pull.

One may prefer to use a screw extension instead of bandage in some cases, when there is difficulty in maintaining the full length of the limb (Fig. 256). This splint allows the patient to raise his shoulders, or even

sit in bed. His other leg can be moved freely, without altering the tension on his thigh muscles, and there is no reflex spasm. Even if the muscles try to contract, they cannot, for the ring of the splint is firm against the tuber ischii. The muscles, therefore, do not remain on the alert, but become quiescent, and starting pains do not occur. Such is the difference between "fixed" and "intermittent" extension.

FIG. 254.—INTRODUCING LIMB THROUGH RING OF THOMAS' KNEE SPLINT.

FIG. 255.—KNEE SPLINT IN POSITION, TRACTION APPLIED.

FIG. 256.—SCREW EXTENSION WHICH MAY BE USED WITH THOMAS' KNEE-SPLINT OR ABDUCTION FRAME.

In using the splint a little attention is necessary to prevent soreness of the perineum. The ring of the splint, being covered with smooth basil* leather, can easily be kept clean; so can the skin. The dressings can be applied without in any way interfering with the action of the splint. When the fracture has occurred through the knee or upper tibia the splint is applied in the same way.

It has often been a matter of astonishment to me that so simple and

* Sheepskin tanned in bark instead of sumac.

effective a splint has not been universally employed. It can be applied in a few minutes, usually without an anesthetic, and one is always sure of good length and good alinement. The fractured limb can be moved in any direction without giving pain, so that transport is easy and safe. I have never yet had to plate or wire a femur in a recent case, and this I ascribe to my using the Thomas splint.

Thomas Bed Knee-splint.—*Measurements Required.*—Horizontal circumference of thigh at groin, length of leg from fork to base of heel.

Splint Measurement.—Add $1\frac{1}{2}$ inches to circumference measurement to allow for obliquity of limb. Add 6 to 8 inches to length of leg measurement to allow for extension pull.

Application.—Apply a strip of adhesive plaster, to which a loop has been sewn on one end, to each side of the leg, with the loop lying at the heel. These should be firmly bandaged on and reach from the heel to as near the lesion as possible. Slide the ring of the splint over the foot and up the leg, pushing the ring well into the groin, and apply the necessary counter-extension on the limb. This counter-extension is maintained by tying the extension loops to the end of the splint by means of a bandage which has been previously passed through the loops.

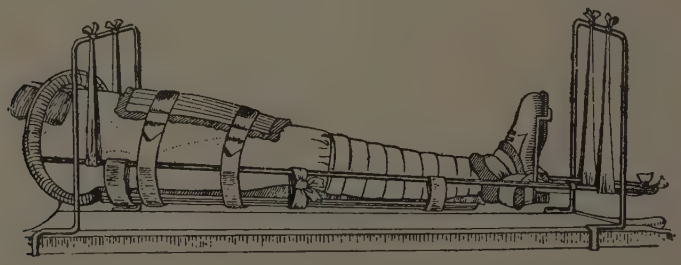


Fig. 257.—Fractured Femur Slung for Transport. (Gray.)

A posterior knee-splint, short enough just to avoid the gluteal fold at the upper end and the heel at the lower end, is then slung between the side bars of the bed splint to support the limb. Local splints can be applied, if required, and the whole bandaged compactly together. Sling or support the foot of the splint to prevent pressure of the heel on the bed.

If the Splint is Too Large in the Ring.—Fix a sufficiently large soft pad in the ring at its junction with the outer bar to prevent the inner portion of the ring slipping from the groin across the perineum.

If the Splint is Too Small in the Ring.—Saw through the ring just in front of its junction with the outer bar; open as necessary.

The Thomas knee-splint is particularly suitable for the immediate immobilization of the fractured leg and for transport. Under these circumstances the boot is kept on and the whole limb suspended by means of the splint to cross-bars fitted to the stretcher (Fig. 257).

Special Points of which Criticism, Modifications, or Additions to the Thomas Splint Have Been Made.—Of course no splint or

appliance is fool-proof. The surgeon's judgment, attention, and experience will always be more important than the materials which he uses. It may be well, therefore, to indicate the actual difficulties which have been experienced in the handling of fractures in the war zone by a number of surgeons, most of whom had no special experience of the Thomas methods and appliances before the war.

These special difficulties may be summarized as follows:

1. Discomfort of the abduction frame when used for long periods.
2. Difficulties in adjustment of the thigh ring.
3. Pressure upon the ischium and perineum.
4. Faulty position of the upper fragment in high fractures.
5. Sagging backward of the shaft.
6. Falling backward of the lower fragment in low fractures.
7. Danger of a stiff straight knee-joint.
8. Faulty position of foot.
9. Ready access while dressing wounds.
10. Adjustment of tension to secure full length.
11. Difficulty of adhesive plaster in presence of multiple wounds and for long cases.

1. **Discomfort of the Abduction Frame.**—It must be admitted that it requires considerable experience with this appliance in order to get the best results from it. In the case of a well-nourished patient whose wounds heal smoothly the difficulties in its use can be easily overcome. But in a thin man with a tendency to pressure sores, in any case where continuous extension is required for several months and when the wounds are of a complicated nature, it is not so easy. In such cases one of the methods described below may be adopted.

2. **Difficulties in the Adjustment of the Thigh Ring.**—An essential element in the correct use of a Thomas splint for fractured femurs being that counter-pressure should be taken by the ring from the tuber ischii, it follows that the ring ought to fit the thigh. But the wounds often require copious dressings, over which in the first place the ring has to be passed, unless the primary cleaning of the wound is to be done after the splint is adjusted—a plan which has obvious drawbacks. Again, the thigh frequently becomes swollen by inflammation and edema, and the ring must, therefore, be large enough to allow for this. Two simple remedies for rings which are too large or too small have been mentioned above. Another is that the ring of the Thomas splint should be suspended by a weight and pulley to an overhead beam, so as to keep the back portion snugly pressed against the ischium. The tendency has been always to use rings which are much too large and which cannot by any means be adjusted.

3. **Pressure Upon the Ischium and Perineum.**—If the ring is so large that it cannot be adjusted then it will certainly press upon the anus and genitals. If it is of reasonable size and well fitted to the ischium, and if full extension is kept up for many weeks, then this process is apt to become sore unless the nurse exercises special vigilance. This pressure can be relieved by hanging the splint to an overhead beam in such a

way that the body weight will to some extent take the place of the counter-pressure upon the ischium, or a weight slung over a pulley may be tied to the end of the splint and thus entirely take the pressure from the pelvis.

4. **Faulty Position of the Upper Fragment in High Fractures.**—Owing to the pull of the iliopsoas and gluteal muscles there is always a tendency for the upper fragment to be tilted forward and outward. But these deformities may be met by abducting the limb and inclining it forward so as to bring the shaft into line with the upper fragment. Only too frequently, however, the deformity is overlooked, and then occurs a marked bowing outward which produces a varoid deformity with great shortening of the leg, or an actual non-union from want of apposition of the fragments. With care this should never happen.

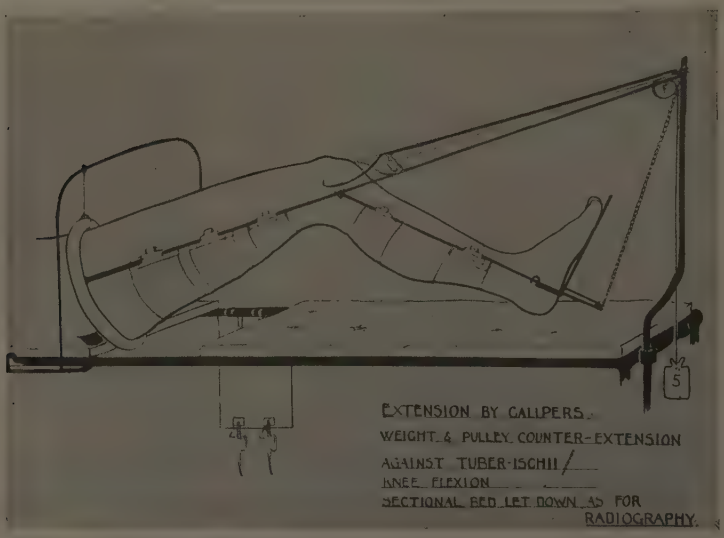


Fig. 258.—Diagram of Pearson's Apparatus.

5. **Sagging Backward of the Shaft.**—In fractures of the shaft, particularly when associated with large posterior wounds, there is a tendency to allow the limb to sag backward. This can only be prevented by careful slinging of the leg to the splint so as to present a good forward curve, which should be maintained after each dressing. This is one of the inherent difficulties in treating an open fracture of the femur. The Thomas splint offers better facilities for dealing with it than any other.

6. **Falling Backward of the Lower Fragment in Low Fractures.**—The pull of the gastrocnemius muscle will always tend to a backward displacement of the distal fragment in low fractures. This can be overcome by adequate slinging applied below this fragment, but unless the surgeon is experienced in its use there may be a difficulty when this sling has to be removed for the application of dressings. Another method is to relax the gastrocnemius muscle by flexing the knee. The

Thomas splint may be bent at the knee or, what is much better, a hinged attachment added to the splint such as is described in Watkin Williams and Pearson's method (Fig. 258).

7. **Danger of a Straight Stiff Knee-joint.**—If a fractured thigh be kept with a straight knee for many months a firm fixation of this joint may result. The danger of this complication will be great in proportion to—

(*a*) The length of the time during which immobilization is kept up. (*b*) The severity and duration of sepsis. (*c*) The implication of the quadriceps muscle in the wounds. (*d*) The proximity of the wounds to the knee-joint.

It can be minimized or avoided by putting up the leg with a bent knee from the outset, or by the use of a hinged attachment to the

FIG. 259.—METHOD OF SUSPENDING FOOT BY GLUED GAUZE TIED TO METAL FRAME. Note that the dorsum of the foot and the tendo achillis remain bare.

Thomas splint. At an early period—*i. e.*, directly after inflammatory action in the wound has been arrested—the knee is moved daily through about 45 degrees, for one movement each day, the knee being kept in a bent position for the greater part of the time.

8. **Faulty Position of the Foot.**—If the foot is allowed to remain without special support it will drop into plantar flexion, the great toe becoming especially affected. The tendency to a rotation of the leg below the fracture also will not be checked. Thus there may be a resulting eversion or, more commonly, an inversion of the foot with equinus and hallux flexus, deformities which minimize the advantages of a well-united femur.

To the ordinary Thomas' splint is attached a wire frame foot-piece, which serves to maintain dorsiflexion and also prevents rotation. The wire frame is either converted into a foot-rest by a transverse strip of canvas, or else a gauze strip is glued to the patient's sole and tied to the apex of the foot frame (Fig. 259).

9. **Ready Access for Wound Dressing.**—When extensive wounds of the thigh exist all of these must be rendered accessible for dressing without disturbing the fixation of the leg as a whole. For this purpose the thigh is slung to the bars of the splint by a number of transverse strips, attached to each side by spring clips. These strips may be made of flannel, canvas, or stout rubber. The latter has the advantage of being readily sterilized. They can be cut from the inner tubes of old motor tires. The use of roller bandages should be entirely avoided for dressing these cases. Dressings on the under surface of the thigh are kept in place by the slings. At the side or in front they are fixed by tucking their edges between the limb and the slings. A roller bandage over the whole limb and splint is, however, of great value during transport.

10. **Adjustment of Tension to Secure Full Length.**—In certain cases the limb may be pulled by manual force to its full length at the first adjustment of the splint, or this full length may be obtained by several subsequent tightenings of the extension straps, this being greatly facilitated by the screw attachment shown in Fig. 256. Then when full length has been secured it is maintained by the fixed or passive extension until complete union has occurred. But the attainment of this ideal necessitates the co-operation of surgeons, nurses, and orderlies who appreciate the object aimed at and the method of its attainment. In actual practice, when each case passes through the hands of many sets of attendants, the length of the leg is often from 1 to 2 inches short. This is due not to any defect in the appliance, but to inexcusable carelessness in its application.

In the first instance the surgeon is satisfied with a rather short leg, and then, what with a large ring which does not fit the ischium and the moving of this ring so that the perineum may be cleaned, the initial shortening is increased. It is for these reasons that many surgeons have preferred to employ the ever-present active extension of a weight rather than trust to the once adjusted passive fixation of the Thomas principle. These systems will be described below.

11. **Difficulty of Adhesive Plaster in Presence of Multiple Wounds and When Used for Long Periods.**—In the figures already given of the adjustment of Thomas' splints the adhesive plaster for extension is represented as reaching high up the thigh. But in many cases the wounds are so extensive as to make this impossible and the adhesive appliance cannot go above the knee. Or there may be multiple wounds below as well as above the knee, and here the difficulty is greater still. Another difficulty arises from the fact that the leg often shrinks very rapidly after application of the first appliance, this being due both to the subsidence of inflammatory swelling or the atrophy of sepsis and disuse. This will necessitate a complete re-application, which must usually be done under an anesthetic.

Attempts have been made to overcome some of these difficulties by the use of glue instead of the zinc oxid and rubber plaster. Glue is cheaper than good strapping, and as it can be applied to the whole surface of the leg below the wounds it holds more firmly. Moreover, it

can be removed easily by the use of hot water. But even with glue the problem of extensive wounds and shrinking limb still remain. Extension which takes its pull from the skin is very liable to make the latter sore if it is kept on for more than a few weeks.

In these special cases—*i. e.*, with large thigh wounds, wounds below the knee, and when extension has to be kept up for several months—it is better to use some form of direct pull upon the bones, by transfixion pin or caliper so constructed as not to penetrate the bone. In those hospitals where these devices have been introduced the tendency has been to use them more and more to the exclusion of adhesive appliances. The greatest care, however, is needed to avoid infecting the bone.

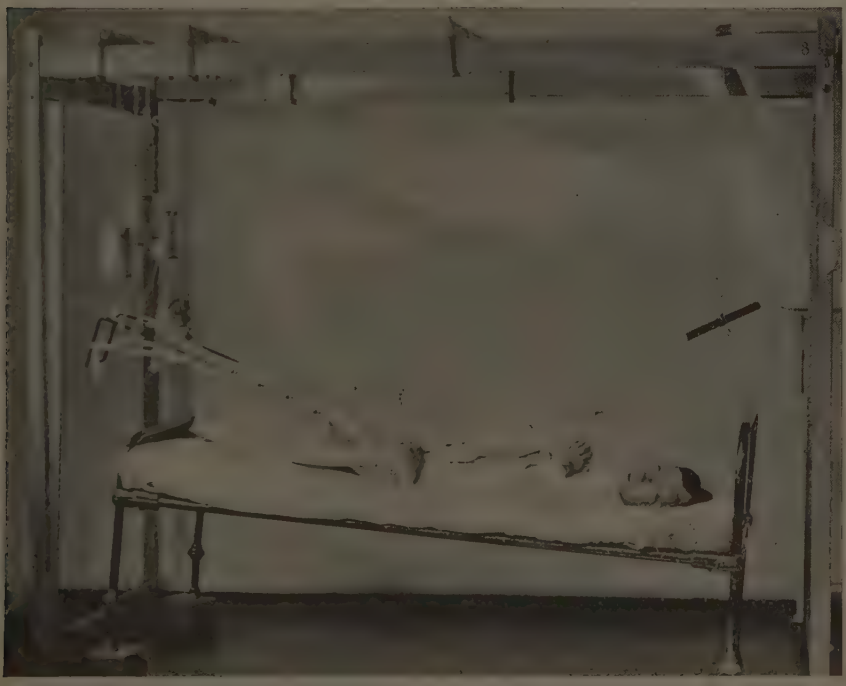


FIG. 260.—SINCLAIR'S COUNTERPOISE METHOD OF SLINGING THE LEG.

Some Special Systems for Treating Fractured Femurs.—Under this heading we will consider the following:

Suspension to overhead beams (Sinclair's apparatus). Special fracture beds (Pearson's method). Cradle splints.

The Balkan Beam and Sinclair's Apparatus.—In the Balkan War of 1911 Borchegrevinck introduced the principle of slinging the injured limb to an overhead bar and relying upon weight extension for an adjustment of the fracture. The value of this appliance has been abundantly demonstrated in the present war. It has usually been a supplementary device used together with the Thomas splint. The latter is slung up to the bar by both the ring and the lower end, and a weight extension

pulling the splint and leg downward is added in order to take over the pressure of the ring upon the perineum.

Sinclair has greatly elaborated this idea. Instead of a single overhead bar he places a wooden frame over the bed, and this frame serves for the attachment of various vertical and horizontal pulleys. The whole leg in the Thomas splint is hung by a system of counter-poising weights so that the patient can be raised in bed for every purpose and the limb can be adjusted in any position. The details of his apparatus are sufficiently explained in the accompanying illustration (Fig. 260).

In order to deal with cases presenting severe back or buttock wounds Sinclair has devised a net suspension apparatus (Fig. 261), in which the

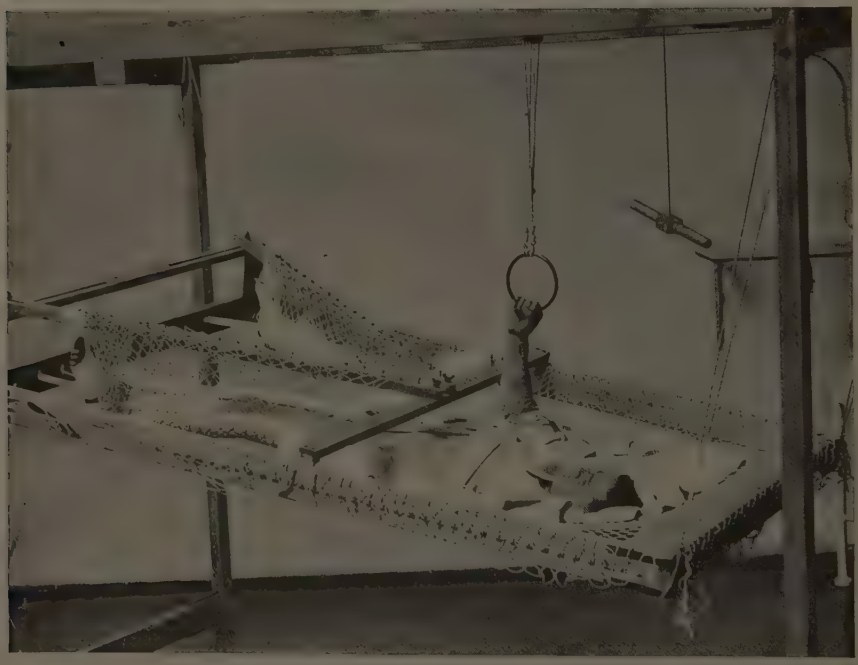


FIG. 261.—SINCLAIR'S NET FRAME.
The body and each leg are slung in a separate net.

body lies on a net slung to a suspended wooden frame and each leg is hung in a separate net sling. This appliance allows for wide abduction of the thighs and for detailed attention to the posterior wounds, which can be exposed by unhooking the corresponding part of the net.

The Special Fracture Bed, Pearson's Methods.—Pearson, who had a very extensive experience both in France and in charge of one of the largest fractured femur hospitals in England, has introduced an admirable bed especially adapted for cases of fractured femur and provided with all the appliances necessary for various adjustments.

The bed is 12 inches higher than the ordinary hospital bedstead. Its special feature is the support of a sectional mattress by transverse

canvas strips, one of which can be removed by a "quick release" so as to expose the wounded region of the thigh for inspection or dressing. Three uprights, one at the head and two at the foot of the bed, support one transverse and two longitudinal, horizontal bars which can be arranged in a variety of ways, so as to sling the leg in the Thomas splint in any position of inclination or abduction. Extension is by means of a special form of ice-tongs caliper which Pearson claims can grip the lower end of the femur without penetration (Figs. 262, 263). To the caliper is attached a cord and weight which act over a pulley.

A hinged portion is fixed to the lower half of the Thomas splint. This serves to sling the leg below the knee which can thus be mobilized as early as may be desired.

Judged by results (Figs. 264, 265), we have not seen any other large series of cases in which such complete restitution of the femur with rapid recovery of the function of the knee-joint has been attained as in that presented by Pearson.

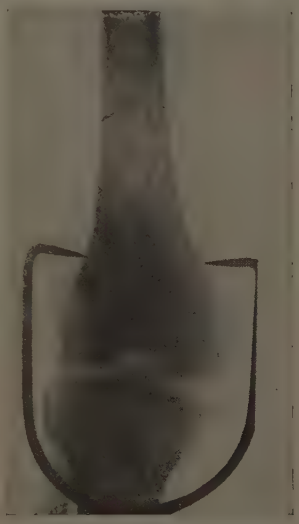


FIG. 262.—PEARSON'S TONGS CALIPER, SHOWING THE GRIP WITHOUT PENETRATION OF THE BONE.

Cradle Splints.—In the early days of the war one of us (H. G.) while serving in the eastern theater of war designed a form of splint which could be made from the ordinary flat and round steel rods which can be obtained from any ironmongery stores. It aimed at being simple and self-contained, and has proved of sufficient value to merit a brief description.

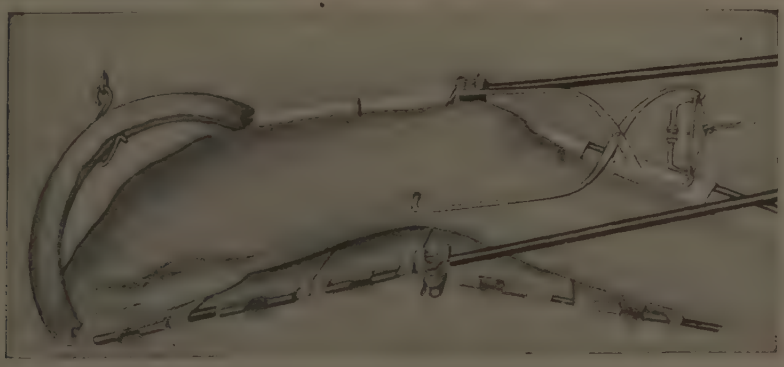
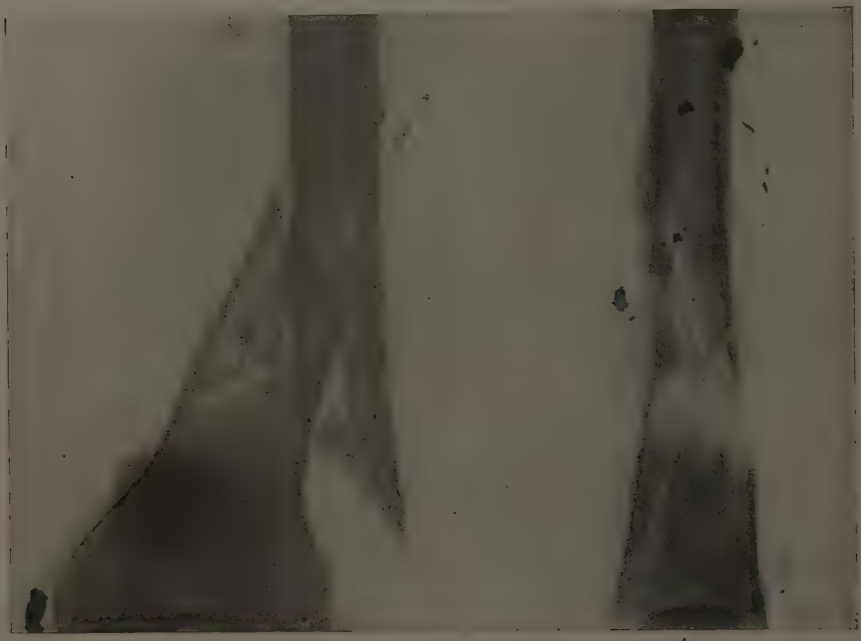


FIG. 263.—EXTENSION OF THE FEMUR BY PEARSON'S CALIPER.

The splint is made in two patterns, long and short, the former being right and left. The long splint is for fractures of the upper half of the femur; the short, for fractures of the lower half of the femur and of the leg below the knee. The patient is nursed on a bed provided with a

three-sectional mattress. The lower section rests upon fracture boards and the splint rests upon this section. The middle section of the mattress is removed for the use of the bed-pan or when dressing high wounds.



a *b*

FIG. 264.—*a*, A VERY SEPTIC CASE, AS ADMITTED TO HOSPITAL SIX MONTHS AFTER WOUNDING. *b*, THE SAME AFTER TWO MONTHS' CALIPER EXTENSION, WHICH IN THIS CASE HAD BEEN APPLIED TO THE MALLEOLI OWING TO THE SEPTIC WOUNDS NEAR THE KNEE.
Recovery with firm union and no shortening. (After Pearson.)

In the latter case the sound buttock is supported by a flat sand-bag. The leg lies with the hip and knee semiflexed, slung in the cradle splint by flannel bands under the unwounded part and by rubber strips in the

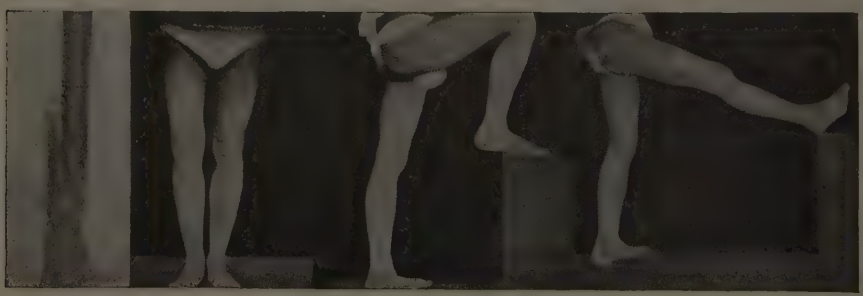


FIG. 265.—THE BONE AND LEG AFTER TREATMENT BY CALIPER EXTENSION. (After Pearson.)

neighborhood of the wounds. Extension is made from a small transfixion pin (4 inches by $\frac{1}{8}$ inch) passed through the crest of the tibia below the tubercle. The pin is grasped by a claw provided with two pulley wheels. The cord attached to the weight is carried over pulley

wheels in uprights fixed to the end of the splint. Only a 5-pound weight is used, thus being multiplied to 10, 15, or 20 pounds by passing the cord over two, three, or four of the pulleys. Mobility of the knee is secured by holding the lower end of the femur with one hand while

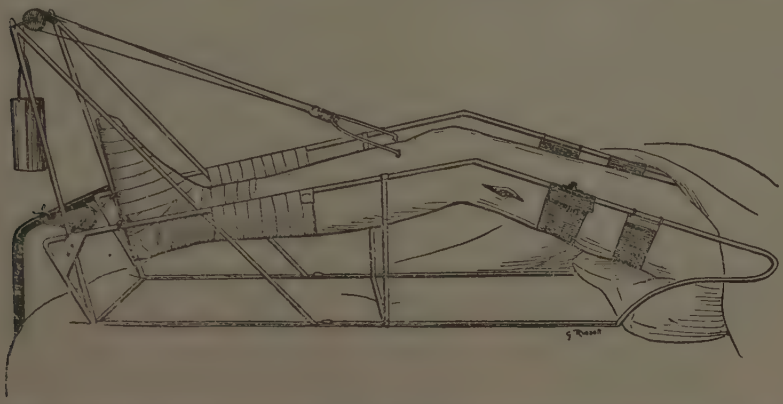


Fig. 266.—Fractured Femur Put Up On the Long Cradle Splint with Extension by a Tibial Transfixion Pin.

raising the leg and foot with the other, once daily. In the use of cradle splints counter-extension is always made by a perineal band passed round the sound hip. This draws up the pelvis on the sound side and anatomically secures full abduction of the thigh of the injured side.

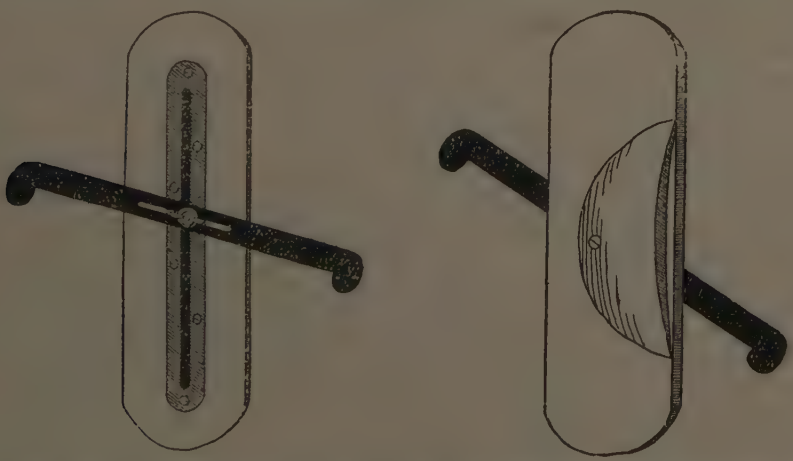


Fig. 267.—Special Foot-piece with Valgus Pad and Adjustable Cross-bar, for Use with the Metal Frame Splints.

On the Functional and Late Treatment of Fractured Femurs.—After the broken thigh has been properly adjusted on one of the above appliances, full length and proper alinement should first of all be secured. Then, if the wound has been properly cleaned, is drained well, and is free from active inflammation the patient should be comfortable

and free from pain. From this moment onward the functional condition of the muscles and especially the mobility of the knee-joints should be maintained as far as is consistent with immobilization of the fracture. The means to be employed to this end are as follows: The leg muscles below the knee should have daily massage. Massage of the thigh and knee are to be used when the wounds are sufficiently healed to allow it. The patella should be mobilized from side to side. The knee-joint should be moved once or twice a day for a single movement of extension and flexion through such an angle as can be done without pain.

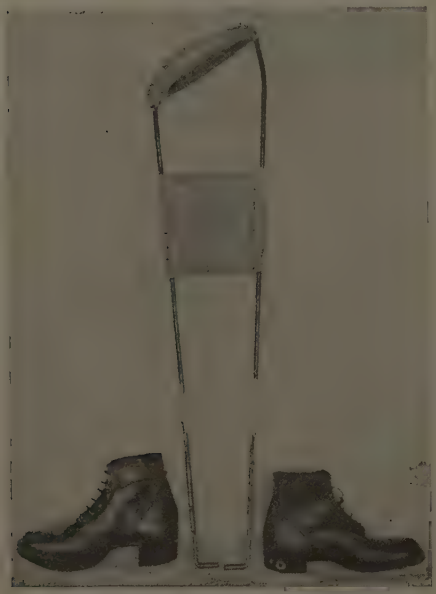


Fig. 268.—Walking Caliper Splint.

As soon as consolidation of the fracture is firm the patient is fitted with a walking caliper modification (Fig. 268) of the Thomas splint, and he should get up and walk with this on daily. As a general rule he should not be allowed to walk without the caliper for a period of three to six months, because there is very real risk of trivial accidents leading to refracture. The walking caliper does not entirely control high fracture of the femur in which there is often a tendency to abduction of the upper fragment, which persists for many months.

In such cases an external gutter splint of padded sheet steel is a most useful safeguard. It must lie snugly against the outer aspect of the whole thigh, from the crest of the ilium to the external condyle of the femur, and be kept there by broad straps. It has the additional advantage of not fixing the knee.

In fractures where there is slow or delayed union consolidation will be greatly promoted by getting the patient up on a caliper splint, supplemented by the daily application of Thomas' congestion bands.

GENERAL PRINCIPLES OF THE TREATMENT OF BONE INJURIES

The general principles on which gunshot injuries of the bones should be treated are divided most conveniently for discussion under the following headings:

Early conditions: 1. Elimination of sepsis. 2. Correction of displacement. 3. Treatment of comminuted fragments.

Late conditions: 4. Sinuses and sequestra. 5. Malunion of fractures. 6. Non-union of fractures.

1. Early Elimination of Sepsis.—This, the underlying problem of all branches of war surgery, has been only very partially solved. At

first it was abandoned as hopeless and the base hospitals presented veritable orgies of septic wounds with the acute types of septicemia, gas gangrene, and tetanus, claiming a heavy toll of victims. Then every few months some new suggestion was made which claimed to save the situation, and for a time we read of great promises, but soon realized great disappointment. First there was pure carbolic acid, then the Watson-Cheyne paste, then the strong salt solution, then Carrel-Dakin, then Bipp, and lastly flavine. But all the time that these new and old suggestions have been exploited the surgeons were perfecting débridement, *i, e.*, the system of excision of wounds and devitalized tissues and the removal of foreign bodies. This contribution is the most practical and valuable that has been made. There seems to us to be good evidence that by early and thorough excision of devitalized tissues perfect and rapid healing can be brought about without any other agency. Success by the Carrel and Bipp methods, on the other hand, is admitted to be dependent very largely on the preliminary débridement. When for any reason excision of the wound track cannot be made early or complete, then we think it is open to doubt whether either the Carrel or any other method can produce speedy sterilization. Under these circumstances free and dependent drainage must be our main agent for assisting the tissues to throw off the infection.

2. **The Correction of Displacement.**—We have already indicated the importance that should be attached to correct splinting. This should aim at three things:

(*a*) The best position of the limb. (*b*) Proper alinement of the broken bone. (*c*) Restoration of the length by axial traction.

But one further point requires consideration in the very early course of an acutely infected fracture. Experience has demonstrated that immediate closure of the wound after excision should always be the aim. Wounds become reinfected if left open. Where immediate closure is not practicable the wound should be packed to prevent the entrance of micro-organisms. In such case traction upon a limb will tend to close all longitudinal incisions and will also place all the soft parts, the muscles in particular, in a state of tension and make them close round the bone. In this early and *ultra acute* stage of septic infection, therefore, the amount of traction made upon the limb should be merely sufficient to secure immobilization with free drainage.

Then when the wounds have become healthy the bone can be restored to its full length. This is done better by the gradual pull and retention than by any sudden forcible act of manual reposition.

3. **The Treatment of Comminuted Fragments.**—This, too, has been a much debated question. On the one hand it has been suggested that *all* the fragments should be *removed* from a septic fracture at the earliest possible moment, preserving only the periosteum. On the other hand, and with equal emphasis, it has been stated thal *all* fragments should be *preserved.* Even if some were loose and fell out during the operation, they should be washed and put back.

In the light of experience we would now assert that the truth lies

somewhere between these two extremes, but much nearer to the latter than the former. Before making dogmatic assertions on this subject we will describe four types of cases of which we have many examples.

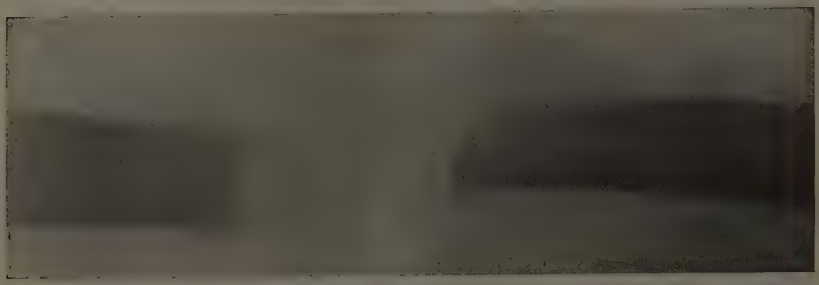


FIG. 269.—GAP IN FEMUR THREE MONTHS AFTER PRIMARY REMOVAL OF ALL LOOSE FRAGMENTS.

(*a*) Case where complete removal of fragments has been made from an entire section of one of the long bones. This type of case is studied best in the forearm or lower leg, when one bone has remained uninjured. The gap made by the removal of the fragments remains indefinitely empty of bone. The ends of the main portion of the shaft adjacent to the gap become rounded and atrophic and there is no regeneration. The same thing happens with a femur (Fig. 269) or the humerus, except that in these bones the tension of the muscle and the contraction of the scar tissue draws the fragments of bone together. Usually by the time they are adjacent to one another so much scar tissue intervenes that no union takes place.

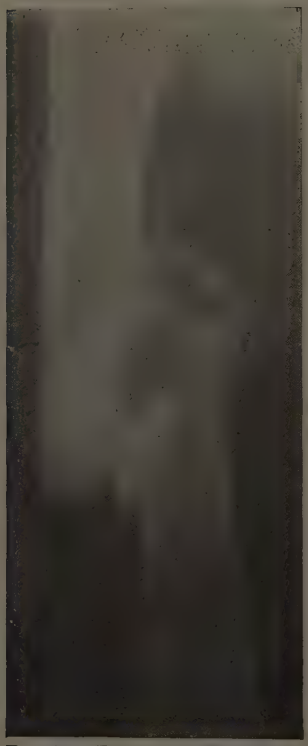


FIG. 270.—FESTOONS OF NEW BONE FORMED BETWEEN THE FRAGMENTS OF A FRACTURED FEMUR. Loose fragments removed two months after wounding.

It may be raised in criticism of any such case that when the fragments were removed the periosteum was not preserved. But, considering that preservation of the periosteum is the cardinal dogma of those who practice this early esquillectomy, we cannot believe that the periosteum has always been sacrificed by those who hold it in such high esteem. And we emphatically state that in many scores or perhaps hundreds of cases of this kind we have seen an absence of regeneration of bone in a gap made by early total removal of part of the shaft.

(*b*) Case where fragments have only been partially removed, leaving bony bridges over a gap in the shaft. When some fragments have been

left in contact with the main portions of the shaft at each end then bony regeneration takes place with great regularity, and it is in proportion to the size of the bridge and the general vascularity and freedom from sepsis of the surrounding parts. A great many of the cases in which surgeons claim to have demonstrated periosteal regeneration after early esquillectomy are of this character.

(*c*) Case where removal of all fragments forming a section of the shaft has been performed after several weeks or months. If after weeks or months of suppuration the surgeon removes all the fragments which originally formed the entire thickness of a portion of the shaft of a bone, then, as a rule, regeneration takes place with restoration of the shaft. If the removal has occurred comparatively early (Fig. 270) then there are only some fragile festoons of new bone bridging the gap, and unless special care has been taken to preserve the length and alinement of the bone, displacement will occur. If the removal has been later, then there is a veritable involucrum or external callus which holds

Fig. 271.—Callous Sheath Formed Between Ends of a Fractured Humerus. The Loose Fragments Were Not Removed Until Four Months After Wounding.

the main fragments in good position, just as in the case of osteomyelitis (Fig. 271).

(*d*) Case where all fragments have been left *in situ*. In a large number of these cases consolidation takes place with more or less thickening of the shaft. In many, however, a sinus persists, and eventually, after all the rest of the bone has become consolidated into a thickened mass, a sequestrum is left in a cavity and suppuration continues until its removal. But in the meantime the main shaft of the bone has become firm and strong and the limb is restored to functional activity.

From a consideration of these groups of cases we think we are justified in reasoning as follows: That bone repair is dependent on vital bone tissue. In the absence of fragments of bone a gap will remain unossified in spite of the preservation of the periosteum. Vital bone fragments in a septic fracture throw out callus which is most abundant where it gets vascular supply, *i. e.*, on the surface of the bone under the periosteum. Fragments of bone may thus actually lay down callus and then them-

selves die and have to be removed, but their temporary preservation will have served to restore bony continuity.

In the early stages of a comminuted fracture all fragments which have vascular supply should be preserved. Every fragment may be assumed to have a vascular supply in the absence of very direct evidence to the contrary. Three conditions in the early stages may require the removal of bone fragments from a comminuted fracture. In a very dirty wound with a great splintering of bone it may be impossible to carry out even the gross cleansing of the tissues without taking away osseus tissue and that pretty freely. Or there may be a loose fragment of bone, the removal of which will greatly facilitate drainage and the subsequent efficient dressing. And lastly, if the bone fragments concern not the shaft but the articular ends, then they should be removed. Whether it is wise under this rule to sacrifice the main articular surface must depend upon circumstances. If the head of the humerus or the bones forming the elbow-joint or the astragalus in the ankle are shattered and septic, then probably a much better joint will result from a removal of the fragments at once than from a conservative policy. But in the knee a free removal of the articular ends of femur or tibia will only be the preliminary to a later excision with arthrodesis. In the intermediate stages, provided there is good drainage and the general condition of the patient is satisfactory, there should be no hurry to open comminuted fractures in order to search for sequestra. It is better to wait for consolidation of the fracture or until the *x*-rays show the differentiation between new porous bone and old dense sequestra. In the late stages when consolidation has occurred, then, and not till then, should dead bone be ruthlessly hunted for and removed.

4. **Treatment of Sinuses and Sequestra.**—For many months or years after a septic fracture infection may remain latent or it may be all the time manifest in the form of unhealed sinuses, usually associated with sequestra. It is the existence of such a state of affairs that has afforded the most plausible argument for those who advocate early total esquillectomy. But against this argument we would urge the following considerations: The first is that in our experience cases in which early total removal of bone fragments has been performed do not always heal up quickly and soundly. The septic lesion remains septic and a further osteitis occurs, with sinuses and late sequestration. Second, this early radical operation is followed by a non-union of the fracture, and third, the conservative plan ensures a restoration of the bone, and a preservation of the function of the limb, while the late sequelæ can be dealt with at a later date.

The **operation of sequestrectomy** when performed late may be anything from the simplest to the most formidable undertaking. The difficult cases are those in which a deeply situated bone, presenting much thickening, is close to important blood-vessels. Broadly speaking, there are two methods of attack: Either the sinues may be cautiously enlarged, the dead bone removed by long forceps, and the cavity cureted and packed; or a wide exposure may be made, the bone cavity

opened up freely, and converted into a shallow groove. No hard-and-fast rule can be laid down in the choice between these two procedures. In many cases it is probably the wisest course to do first the simple operation, and then, if healing does not occur, the more difficult.

The **obliteration of bone cavities** is usually a matter of some difficulty, owing to the rigid and avascular nature of the tissues and their septic condition. There are three methods of filling or obliterating such cavities: First, by filling the cavity with wax, fat, or muscle; second, by removing the walls of the cavity sufficiently to allow the soft parts to cover it in; third, to force the walls of the cavity together.

There is little to be said in favor of filling with foreign materials or with free fat. Such methods demand for success a degree of sterilization of the walls of the cavity which is seldom possible. If the cavity be sufficiently shallow to allow of a neighboring muscle to be stretched into it as a pedicle flap, this is a good operation, but still liable to disappointment. Certainly, whenever the structure will allow of it, the second or third plan is the best.

5. **The Malunion of Fractures.**—The causes of malunion of fractures are all found in the neglect or failure of treatment at an early or late stage.

Concerning faulty treatment at an early stage we need make two remarks: The first is that the most glaring examples of malunited fractures are found in the cases of men who have been frequently sent from one hospital to another, *i. e.*, when there has been no continuity of treatment. The other is that a much higher standard has been accepted by the profession as right and reasonable than was the case in the early years of the war. It has been demonstrated beyond dispute that fractures can be so treated as to give full length, good alinement, and proper function of the joints, and nothing short of this must satisfy us.

But in gunshot fractures there is a factor in the production of malunion which was hardly recognized before the war. That is the very slow nature of union after sepsis and the soft yielding character of the callus which is formed. In many instances a man has received perfectly adequate treatment until the date of consolidation of his fracture—then he is allowed to get up. If no adequate support is given to the leg it bends under the weight of the body or in response to unbalanced muscular tension. Therefore surgical care should be systematically given to all cases of fractured femur for six months after the patient first gets up, and adequate precautions taken to prevent secondary malunion.

From the point of view of the results on the function of the limb, malunion of fractures of the long bones may be divided into:

Malunited fractures of the shaft and malunited fractures of the articular ends.

The latter group, containing all those cases in which irregular union, excess callus, and alteration in the axis of the joint, have interfered with the action of the articulation will be considered later.

Malunion of Fracture of the Shaft.—If we confine ourselves to any degree of malunion which is responsible for loss of function and which

may require operative treatment, we find that this condition is very common in the femur (Fig. 272), but comparatively rare in all other long bones. It will be convenient, therefore, to concentrate attention upon femoral malunion and then to consider briefly other instances of malunion which may require operative interference.

There are three elements in the displacement associated with malunion of the femur which exercise a varying degree of influence upon

Fig. 272.—Typical Malunion of Femur with Angulation Outward. (McMurray's case.)

the function of the leg. These are overlapping, angulation, and rotation. Most often more than one of these elements coexist. It is especially common to find overlapping and angulation in the same case. If sufficient traction has been applied to the limb to secure alinement then there will be but little overlapping, and it is still more true to say that if enough traction has been used to prevent overlapping it is very unlikely there will be any angulation. The moral of this is that any

method which fixes the thigh in the right line and obtains full length is secure against malunion, quite apart from *x*-ray findings.

Overlapping and angulation both produce real and functional shortening of the leg.

Owing to the dangers of latent sepsis and the mechanical difficulties of overcoming the contraction of dense scar tissue correction of malunion of a gunshot fracture is a matter not lightly to be undertaken. Therefore it is of great importance to distinguish clearly what degree or type of malunion requires operation and what is better left alone.

Cases in which Operative Interference is Indicated.—Serious loss of walking function.

For the correction of angulation: (*a*) When it interferes with joint function. (*b*) When walking is made difficult by adduction of the lower fragment.

To correct excessive shortening: (*a*) When there is not an excess of scar tissue, and the chances of extension are good. (*b*) When rotation complicates angulation or shortening.

Cases in which Operation is Either Unnecessary or Should Be Postponed.—1. Where the shortening is due to overlapping in the presence of much scar tissue. 2. Where function is rapidly improving. 3. Where serious sciatic nerve lesion exists. 4. Where sinuses exist with the evidence of recent infection.

We must carefully distinguish between real shortening and that which is effective or apparent. Real shortening, as the name implies, means that one limb is actually shorter than the other. Apparent shortening is due to pelvic obliquity. Apparent and real shortening often coexist. Real shortening is estimated by measurement from the anterior superior spine of ilium to the malleolus. Apparent shortening, by measurement from the umbilicus to the malleolus. If the hip-joint is not partially or wholly ankylosed the apparent shortening can easily be overcome by voluntary effort or by extension, and therefore no operation is needed to correct it.

In war injuries the tilted pelvis is often due to a functional graft upon an organic lesion. It disappears under anesthesia. It arises often from the effort made by the patient with outward bowing of his fracture to bring the legs parallel. Without that effort the limbs would cross. As, however, the adduction of the lower fragment is not a fixed one, the hip-joint being free, every effort should be made by exercise and volition to abduct the limb without raising the pelvis, and in this way improve walking.

A simple way of estimating the shortening is by placing a block under the foot, and when the two anterior superior spines of the ilia are exactly level the block will indicate the addition which is necessary to place on the boot.

The man may, for a time, be made to walk with a short limb and boot in order to test the solidity of the fracture, the freedom from danger of recrudescent sepsis, and to assist in the strengthening of bone and muscle.

The smooth working of a limb depends on preserving the true axis and movement of the joints so that the stresses of muscular action may act across the joint in normal lines. Otherwise abnormal stresses will produce abnormal strains, for we are dealing with living bones in accordance with Wolff's law, which is the physiologic equivalent of that universal law that strain is proportional to stress.

In dealing with fractures of the femur the first consideration is to secure and maintain a true anatomic alinement of the bone so that the axis of movement of the joints at the two ends of the bone may retain their correct relative positions. The ideal aim is to bring the fragments

FIG. 273.—TYPICAL CASE OF MALUNION OF UPPER END OF FEMUR BEFORE AND AFTER TREATMENT. (Naughton Dunn's case.)

at the seat of fracture into correct reposition. Experience, however, has amply demonstrated the fact that meticulous exactness in replacing every fragment is not necessary to a perfectly good functional result. Faulty alinement is due to angulation, and this may occur either if the bone overlaps or if there be end-to-end apposition. It always results in cross-straining of the fracture, and an erroneous deflection of body weight upon the joints above and below the fractures. *Faulty alinement is a deformity which is always preventable.*

Angulation is that element in malunion which should be the chief argument in favor of an operation. This is because angulation for

many months and even years is an unsound form of malunion, *i. e.*, it is liable to be both painful and progressive, the soft new bone yielding more and more under the body weight; also that angulation is the most crippling element in malunion because it must necessarily disturb the axes of the joints above and below, and lastly, because it is susceptible of easy and simple operative correction. Of the various types of angulation, the commonest, viz., angulation outward and backward, are those most necessary to correct, the former because it adds to the effective shortening of the leg, and the latter because it leads to genu-recurvatum. It is seldom that simple rotative deformity requires operative correction because in the absence of more serious deformity, as it is so largely capable of correction by walking exercises; but added to these other deformities it may afford an additional reason for intervention. If malunion is a simple overlapping without serious angulation and if there is a mass of scar tissue overlying the fracture between it

FIG. 274.—SAME CASE AS SHOWN IN FIG. 273, DURING TREATMENT ON AN ABDUCTION FRAME. (Naughton Dunn's case.)

and large wounds, then it is not wise to attempt operative correction. Such operation will present the maximum of difficulty and danger with the minimum of functional improvement. Lengthening the bone involves a wide breaking up of bony union and necessitates tearing or stretching the scar tissue. This, in its turn, if it does not cause serious septic recrudescence, will probably lead to the wounds breaking down as the result of tension. If, as is usually the case, malunion combines both elements, overlapping and angulation, it is often the most prudent thing to correct the latter, while leaving the former.

We trust that we shall not be thought, after all we have said and written here and elsewhere, to minimize the importance of securing full length in a fractured femur. If a case is presented with overlapping at any period before firm union has taken place we think that this should be corrected, and the best method of correction is by simple extension with retention or by a weight applied to the condyles by a caliper which

does not enter the bone. But when such a case is presented after firm osseous union has occurred then we think that it is too late for correction by open operation. *It is in part because late operative correction of an overlapping fracture is so difficult and dangerous that we should insist on the importance of securing full length at the outset.*

Operative Treatment of Malunion of the Femur.—The operation of choice should always be an osteotomy of the simplest possible character. A great deal of what has been said above about the choice of cases for operation might be summed up by saying that these cases should be

Fig. 275.—Skiagram of Case Shown in Fig. 273 Before Treatment.

operated upon in which a simple osteotomy would serve to correct the deformity (Figs. 273–276).

The incision is made on the outer aspect of the thigh and is of such size as to admit a broad osteotome. The bone is three parts chiseled through and the remainder is broken. The limb is put up on a Thomas splint or, in the case of a high malunion, on an abduction frame or plaster of Paris. A special word of caution is necessary about after-treatment: the causes which produced the deformity are still active, while the sclerosed bone heals and consolidates but very slowly. Therefore efficient protection against recurrence of deformity must be provided for

six or twelve months. This, where possible, should take the form of a walking caliper, although a reinforced plaster splint may occasionally be advisable.

There is but little to be said in favor of a cuneiform as distinguished from a linear osteotomy for these conditions.

One further point requires consideration—the exact site of the osteotomy in relation to the original fracture. Whenever the deformity can be equally well corrected by dividing the bone through the shaft near the fracture, as by a division through the fracture line itself, the

FIG. 276.—SAME CASE AS SHOWN IN FIG. 273 AFTER TREATMENT.

former is the better practice. The bone and the soft tissues through which it is approached will be much healthier, less liable to sepsis, and more apt to unite quickly.

Elaborate open operations are very seldom justified in the treatment of malunited fractures of the femur. In simple cases where an osteotomy will correct the deformity, it is a risk which has no advantage to screw on a plate to the surface of the bone. In difficult cases with overlapping it is better to be content with correcting angulation than to cut out a

piece of the bone to get end-to-end union. Restitution of form by traction or leverage is difficult and dangerous in the presence of scar tissue (Fig. 277). These dangers and difficulties are increased by any attempt at efficient mechanical fixation by plates and screws.

Malunion of the Tibia.—The only types of malunion which require operative treatment are those which disturb the axis of the ankle-joint. Forward angulation of the tibia should be treated by a cuneiform osteotomy, the fibula not requiring division. Internal angulation with valgoid deformity of the foot requires a cuneiform osteotomy of the tibia associated with a simple osteotomy of the fibula.

FIG. 277.—EXTENSIVE SCARS ON A BADLY MALUNITED THIGH, ILLUSTRATING THE DIFFICULTY OF OPERATION.

Malunion of the Radius.—Owing to its great functional importance the radius is seriously affected by any degree of malunion. The deformities of the radius are of two kinds, which often occur simultaneously. The first is a rotary deformity, the distal end being pronated while the upper end is supinated. The other consists in a valgoid position of the hand, *i. e.*, lateral deviation toward the thumb, the head of the ulna being very prominent. The lateral deformity in these cases consists in a fracture of the shaft of the radius, the fragments having fallen inward and united in close adhesion to the ulna. If the curved form of the radius has been preserved and supination lost from the faulty position in which the forearm was put up, then the treatment is simple. It should consist in a simple osteotomy of the radius just above—*i. e.*, proximal to—the insertion of the pronator radii teres. If after the section the ends of the bone tend to slip past one another, they should be held in place by the insertion of a bone-peg 1 inch long and about $\frac{3}{16}$ inch thick, having a slight enlargement at its center. The forearm is then put up in full supination. If supination is prevented by contraction of the pronator teres, a condition rarely met with, the tendon of this muscle should be cut or elongated by a **Z** incision. In the common deformity where the fragments of the radius are angulated inward and attached to the ulna the problem is much more difficult (Fig. 278). Mere osteotomy with reliance on muscle suture to prevent cross-union is very unsatisfactory. The most effective way to restore the outward curve

to the radius which is essential for the correct position of the hand and rotation is to lengthen the bone by means of a graft. This operation will be described in the following section.

NON-UNION OF FRACTURES

In military surgery most cases of non-union of fractures are due to one of three causes, viz.:

1. Loss of substance. 2. Interposition of soft parts. 3. Sclerosis of the bones.

As minor causes may be mentioned:

4. Overextension (especially in the humerus). 5. Ill-advised plating operations.

1. The loss of substance may be primary by the action of the muscle or the activity of the surgeon, or it may be secondary to septic necrosis of the ends of the bone. It almost inevitably leads to non-union in the case of one of the forearm or lower leg bones, where the companion bone remains sound. In the humerus or femur, if axial traction is not kept up too long, the gap may be obliterated by the main fragments coming together.

The interposition of the soft parts is a cause of non-union most frequently in the femur, and there at the junction of the upper and middle thirds. Such non-union is preventable by proper traction and the correct alinement of the fragments, provided this is done before the ends of the bone have become indolent and sclerosed.

Sclerosis of the ends of the bone is the inevitable sequel to sepsis and want of apposition of the fragments, and it is greatly favored by operative procedures which strip off the periosteum from the bone ends and thus rob them of their blood-supply.

The relative frequency of non-union in the long bones (exclusive of the fibula) is seen in the following summary, compiled from 60 consecutive cases:

Femur, 26.4 per cent. Humerus, 22 per cent. Radius, 12 per cent. Ulna, 12 per cent. Radius and ulna, 5 per cent. Tibia, 6.6 per cent.

The most notable points in which this frequency incidence differs from that of civil surgery is the high proportion of non-union in the femur, radius and ulna, and the comparatively low incidence in the tibia. The high incidence in the femur is due largely to faulty early treatment which has allowed the fragments to become widely dislocated. In the case of the radius and ulna the conditions are common because the companion bone prevents closure of a gap by contraction. The comparative rarity of non-union of the tibia is because cases with much loss of substance usually suffer amputation.

The Anatomy of Ununited Fractures.—There are two different types of cases—viz., the gap fracture and the pseudarthrosis.

The gap fracture is seen in the case of the radius, ulna, or tibia when the companion bone has remained intact. The bone ends are usually conical or rounded, their substance is much atrophied, consisting of a thin shell containing fatty marrow. Between the bone ends is a mass

of scar tissue in which bone débris and scraps of metal are often embedded (Fig. 278).

The pseudarthrosis is found in non-union of the humerus and the femur (Fig. 286). The bone ends are densely sclerosed and present osteophytic outgrowths in proportion to the length of time that the condition has existed. The medullary cavity is obliterated by solid eburnated bone for a considerable distance and the surface of the fragments is closely invested by a fibrocartilaginous envelope. Between the bones is found a mass of white scar tissue in which a synovial cavity with glairy fluid contents may have developed.

It is important to bear in mind these structural changes in the bone because they have such an important bearing upon treatment. The fragile atrophic bone in the gap fracture presents a marked contrast to the dense sclerosed bone of the pseudarthrosis, but both conditions have this in common, that there is a conspicuous absence of cellular elements.

FIG. 278.—GAP FRACTURE OF RADIUS.
Note the atrophy of the bone as compared with the ulna and also the dropping in of the fragments toward the ulna. The same case is seen after treatment in Fig. 297.

Non-operative Methods of Treatment.—Non-operative measures of practical utility consist of: (*a*) Massage and percussion. (*b*) Active and passive congestion. (*c*) Plaster immobilization.

By deep massage, percussion, and congestion a state of vascular activity in the ends of the bone is set up which promotes callous formation and bony union. Many years ago it was pointed out by Thomas that the mere hammering upon the ends of the bone, associated with the tying of rubber tubes above and below the fracture so as to cause local congestion, would often bring about rapid healing of a delayed union. The tubes are tied about 3 to 8 inches above and below the fracture, and kept on at first twenty minutes at a time and later for several hours daily. In cases of ununited fractures of the femur the patient should be allowed to walk in a caliper splint while the congestion tubes are worn. Plaster immobilization has a rôle in the treatment of a few cases of delayed union. When a septic fracture, associated with a wound or sinus, is long in uniting, when there is a considerable inflammation as evidenced by pain and rise of temperature—then a well-applied plaster is often of service. It is assumed, of course, that any

Fig. 279.—Breaking Down of a Cutaneous Scar After a Bone-grafting Operation.

gross cause of sepsis, such as a sequestrum or foreign body, has been removed and that the fragments of bone are in good contact. By cutting a suitable window in the plaster opposite the wound a local congestion of the latter is produced which is favorable to healing.

Operations for Non-union of Fractures.—Before detailing the special operations for ununited fractures we must consider certain necessary preliminary conditions. These are the elimination of latent sepsis, the removal of scars, and the restoration to function of the muscles, nerves, and joints.

Latent Sepsis.—It has long been known that infective organisms might lurk in the tissues for months and years, and only spring into activity on the occurrence of general debility or local trauma. Of this, the tubercle bacillus is the classical example. Further, we knew that

FIG. 280.—PEDICLE SKIN-GRAFT FOR FOREARM PRELIMINARY TO A BONE-GRAFT.

such germs as those of enteric fever or tetanus might exhibit the same latency. But it is only since the present war that we have been fully alive to the fact that the ordinary pyogenic organisms and the B. coli could lie dormant in the tissues under a soundly healed wound, and then cause virulent suppuration if their seat was opened up by an operation. At first it was assumed that by waiting a few months the tissues would become sterile, but it is now recognized that in some cases, notably those presenting much scar tissue and those where the bone has been comminuted, the infective germs may remain potent for evil almost indefinitely. In order to combat this latent sepsis it is not sufficient to merely wait, but active steps must be taken to remove all sequestra, unhealthy bone and scar tissue, and to restore the healthy vascularity to the remaining tissues. The actual period of waiting before operation should not be a hard-and-fast one. Certainly it should never be less

than three months from the healing of the wound. If there has been much injury of the bone, long sepsis and much scarring, and if an elaborate reconstructive operation is required, then it is better to wait for six or twelve months after the wound has healed, during which various preliminary precautions are taken.

Removal of Scar Tissue (Fig. 279).—Extensive cutaneous scars must be replaced by good skin with ample subcutaneous fat. In the thigh this

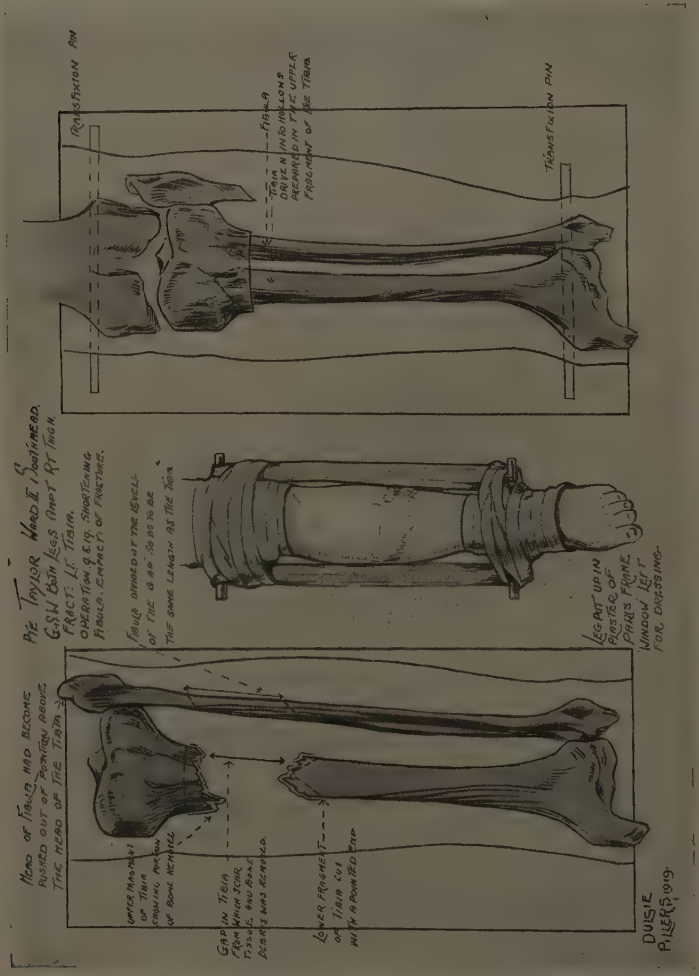


Fig. 282.—Operation of Impaction of a Gap Fracture of the Tibia.
The patient had lost the other leg and therefore the length of the one leg was unimportant.

can usually be done by mere excision of the scars and a drawing together of neighboring skin. In the arm and forearm it is to be done by taking pedicle flaps from the chest or abdomen (Fig. 280). At the same time that the cutaneous scar is removed, or as at special operation, if there are no bad skin scars, all the deep scar tissue should be dissected out as far as possible, together with the ends of the bone abutting upon the

Fig. 281.—Ununited Fracture of Tibia Showing Large Adherent Scar Preventing Bone-grafting.

ununited fracture. This scar tissue should be sent to the pathologist and, according to his findings, an appropriate vaccine given (Fig. 281). The object of this thorough removal of scar tissue of the skin, deep tissue, and bone is to get rid of the lurking place of the infective organism, to remove tissue of low vitality, and also to do away with the troublesome oozing which always takes place when scar tissue is cut into and which prevents the attainment of a dry wound.

The Operations for Ununited Fractures.—These are: Refreshing of ends of the bone. Impaction. Oblique or step-cut union. Bone-grafting.

Refreshing of Ends of the Bone.—This has already been referred to incidentally as a part of the removal of scar tissue. If there is no large gap held apart by a companion bone or if, as in the case of the humerus, there is no objection to eliminating the gap by shortening the bones, then mere sawing off their indolent extremities may be all that is necessary. If the ends of the bone are densely eburnated it is wise to drill each in a longitudinal direction by means of a $\frac{1}{8}$-inch drill until each drill hole bleeds freely. This will provide a channel for new vessels and osteoblasts to reach the seat of fracture. If it is possible to unite the ends of the bone by stout tendon sutures or by a single wire this should be done, and the limb put up in a plaster-of-Paris bandage, which will preserve the bone from distraction.

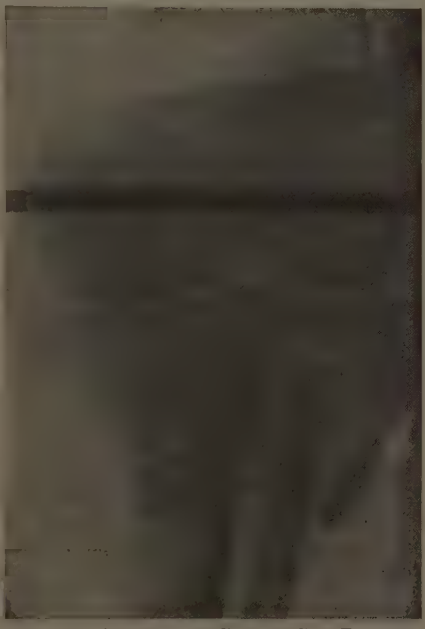


Fig. 283.—Skiagram of Case of Gap Fracture of the Tibia Treated by Impaction.

Impaction of the Fragments.—This operation is one which is only suitable in certain cases. In the humerus, when there has not been much loss of substance, the lower fragment may be pointed, while the upper is drilled and the former driven up into the latter.

In the lower leg the type of case for which this operation is suitable is one where one leg has been lost, and the other has a gap in the upper part of the tibia, covered by a large thin scar difficult to replace (Figs. 282, 283). A piece is taken out from the fibula, the lower end of the tibia is pointed, and the distal portions of the tibia and fibula are driven into the head of the tibia. Impaction may be preserved by appropriate splinting and more rarely by passing a transfixion pin through the condyles of the femur and a plaster bandage above this pin and below the sole of the foot.

In rare cases a similar operation may be done in the forearm. This is where a gap exists in the radius, with a short wide lower fragment,

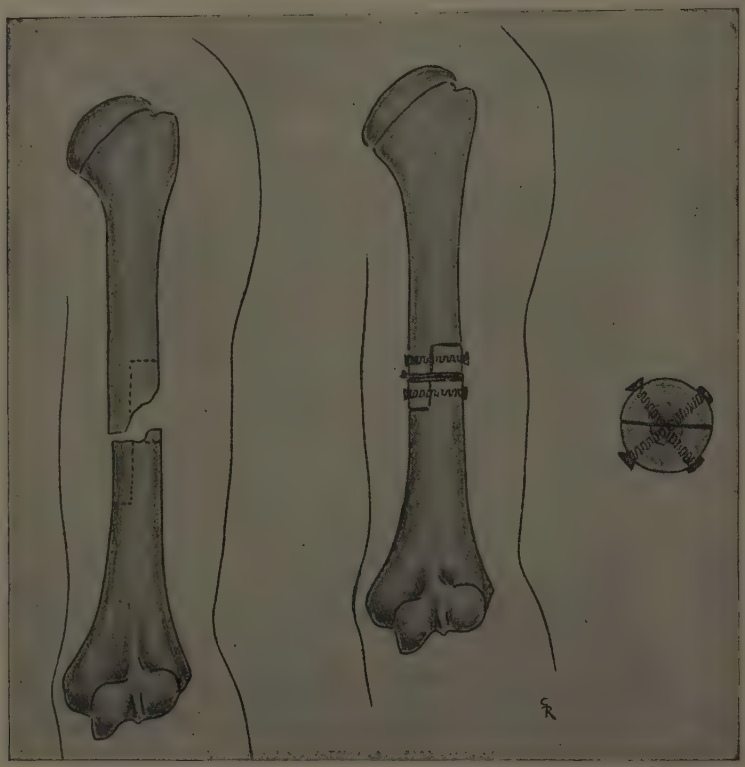


Fig. 284.—Diagram of Step-cut Operation for Ununited Humerus.

and where there has been much scarring and destruction of the tendons. The ulna is shortened and the proximal part of the radius is then im-

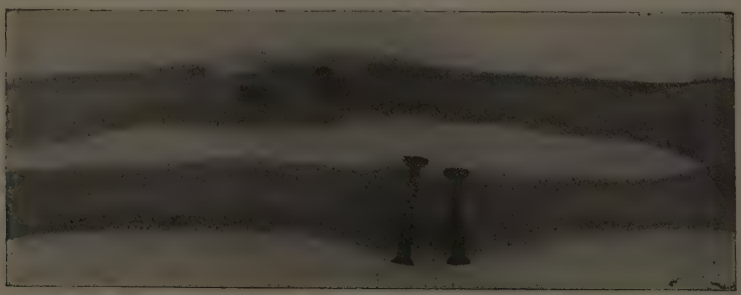


Fig. 285.—Step-cut Operation for Ununited Fracture of Radius and Ulna. The patient was able to return to full military duty.

pacted into the distal. If the soft tissues of the forearm are intact it is, of course, much better to restore the gap in the radius by means of a bone-graft.

The Oblique or Step-cut Operation.—This is the operation of choice in ununited fractures of the humerus and femur and where both radius and ulna are simultaneously affected.

The bone is cut either by oblique saw cuts or by double cuts in the form of a step and then fixed together by means of screws or bolts or wire. The details of the operation are sufficiently indicated by the accompanying figures. Of the two methods, the step operation is the more reliable. In the case of the humerus ample overlapping should be provided for. Kangaroo tendon or bolts through the holes drilled

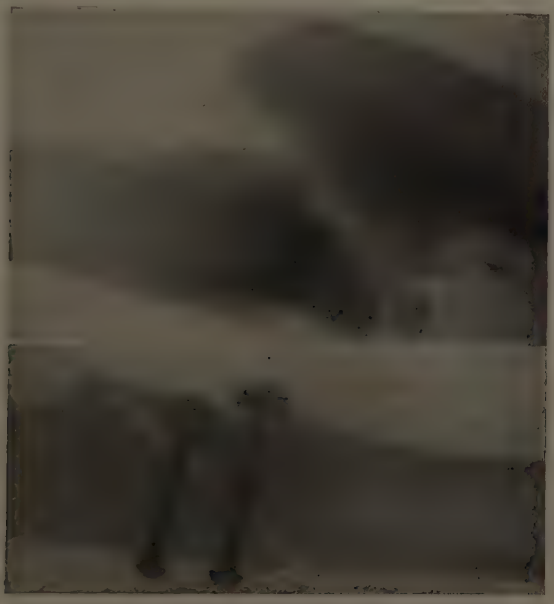


FIG. 286.—PSEUDARTHROSIS OF FEMUR OF ONE YEAR'S STANDING AND THE SAME AFTER BOLTING.

in the bones will maintain apposition. The arm should, however, always be placed abducted from the side (Figs. 284–286).

BONE-GRAFTING

The replacement of a portion of one of the long bones, lost by injury or disease, by means of an autogenous graft would be a comparatively simple matter if the graft could always be laid into healthy tissues directly after the gap was made. This is the problem in the experimental form. But as regards the clinical case the practical difficulties are much greater owing to the atrophied or sclerotic bone, indolent scar tissue, latent sepsis, and a high degree of atrophy of the muscles, with correspondingly poor blood-supply.

The following statements are generally accepted:

1. That a living autogenous graft is, on both practical and theoretic grounds, preferable to all others.

2. That such a graft under favorable circumstances will take an active share in osteogenesis (Figs. 287–290).

3. That although periosteum is not essential for the taking of the graft, it is a most potent factor in securing rapid vascularization and osteogenesis.

4. That the crest and anterior surface of the tibia form the best source of the graft when the gap to be filled is in one of the long bones.

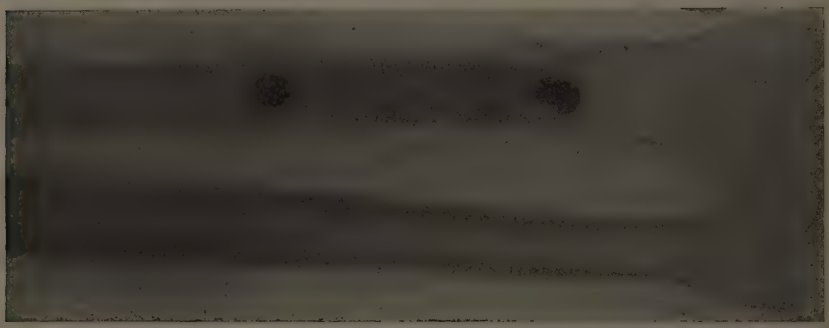


FIG. 287.—BONE-GRAFT IN A GAP FRACTURE OF THE RADIUS.

5. That when mere fixation of bones, apart from the filling of a gap, is required, then the use of boiled bone-plates, pegs, screws, and mails made of bone or ivory is of great practical utility, as this structure becomes rapidly vascularized and incorporated in the living bone.

The Limitations of the Sliding Inlay Graft Method.—In dealing with certain types of simple fractures it has been demonstrated by Albee with great success that by the use of a twin saw a portion of the cortex of one fragment may be slid down into a groove so as to bridge the

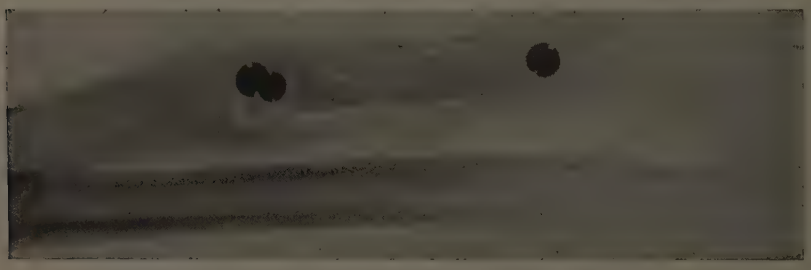


FIG. 288.—SAME CASE AS FIG. 287 AFTER THREE MONTHS.
Note the central sequestrum in the graft and the epi-osteal new bone.

fragments. In this way a living union is secured *per primam*. But this method is only suitable for recent clean cases without loss of bone, and however much we may admire the ingenuity of the method and the technical skill with which it is carried out, we cannot avoid the criticism that, like plating of recent fractures, it is often unnecessary. In gun-shot fractures the sliding graft is seldom of much avail. If the case is one of pseudarthrosis, both the graft itself and the bed in which it is laid consist of dense sclerotic bone, whose absence of osteogenic activity

is the proved cause of the non-union. If used for a gap fracture the slender graft will have to span a space where it has no bony bed—the graft itself and the fragments to which it is attached are already atrophied and indolent.

Unfortunately, these principles are not sufficiently understood, and many cases are being treated by this method, with disappointment to the patient and discouragement to the surgeon (Fig. 291).

Fig. 289.—Same Case as Fig. 287 After Six Months. The Bolts and Central Sequestrum Were Removed After the Last Picture.

The Cortical Graft.—This type of operation has been found most useful in the tibia. In this part it is absolutely essential to get rid of all weak scars from the front of the skin by a preliminary operation. Then after a suitable interval a graft is cut from the anterior surface of the opposite tibia and fitted into a prepared slot in the following manner:

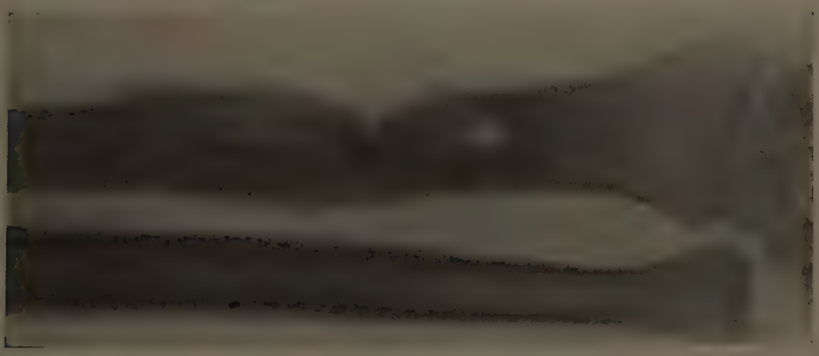


Fig. 290.—Same Case as Fig. 287 After Nine Months, Showing Firm New Bone Laid Down by the Graft.

Two curved aluminum plates 6 inches long are prepared. One of these is $\frac{1}{16}$ inch wider than the other, being then $\frac{1}{2}$ and $\frac{7}{16}$ inch wide. Each is provided with a series of small holes for the reception of short wire nails. These plates are to serve as templets to measure and cut the groove and the graft. The fractured tibia is exposed by a curved incision, so that the suture line shall avoid the front of the leg. The bone

being exposed, the periosteum is raised from it by an I-shaped incision so as to lay bare a surface rather more than 6 inches by $\frac{3}{4}$ inch. The

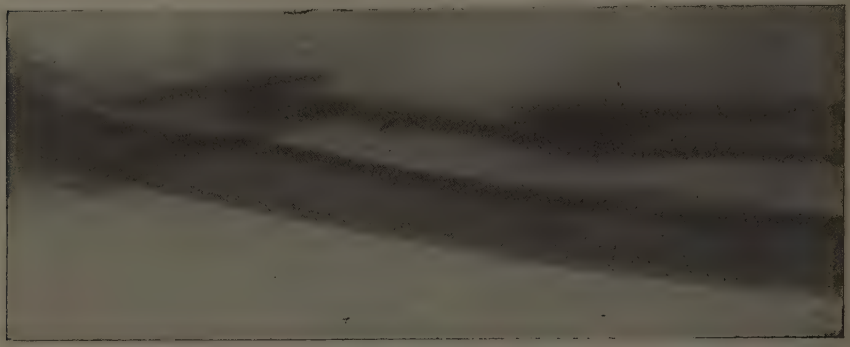


FIG. 291.—GAP FRACTURE OF THE RADIUS WHICH HAD BEEN TREATED BY A SLIDING BONE-GRAFT. Taken six months after operation. There is no new bone and no union between the graft and its bed.

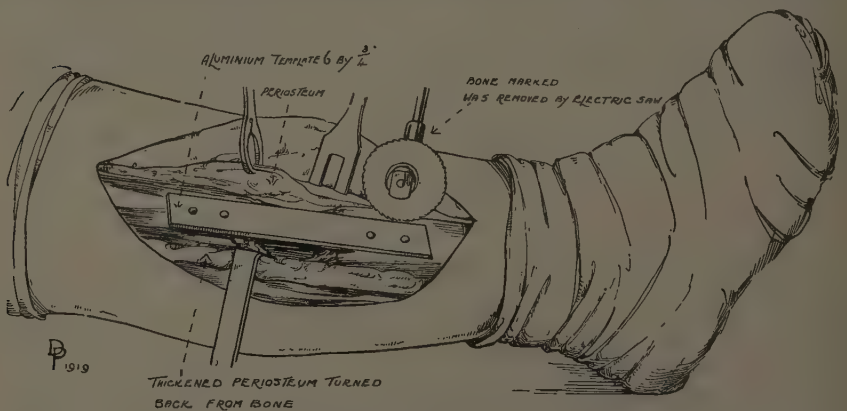

ALUMINIUM TEMPLATE 6 BY ¾
PERIOSTEUM
BONE MARKED WAS REMOVED BY ELECTRIC SAW
DP 1919
THICKENED PERIOSTEUM TURNED BACK FROM BONE

FIG. 292.—CUTTING GROOVE FOR GRAFTING A FRACTURED TIBIA.

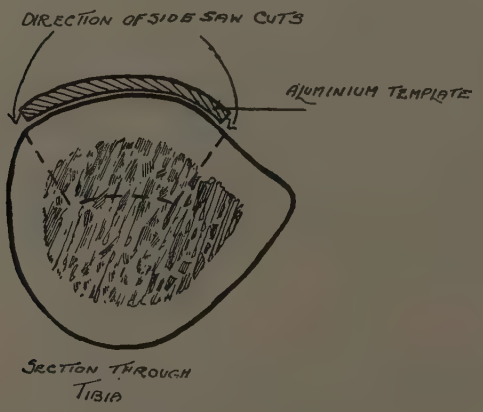


FIG. 293.—SIDE SAW-CUTS.

fibrous tissue is removed from between the fragments and the ends cut fresh. The leg being held in correct alinement, the narrower of the

templets is nailed on to the bone so as to hold securely while the bone is sawn (Fig. 292). With a motor saw the groove is cut out by four cuts on the four sides of the templet. The side saw-cuts converge toward

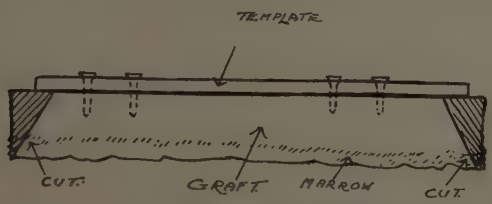


FIG. 294.—END SAW-CUTS.

the axis of the bone, so that in transverse section the groove will be wedge shaped. The end saw-cuts undercut the surface of the bone. By means of a fine chisel the groove is cut clear of the bits of bone and the latter are preserved to help in filling in the gap. The groove is

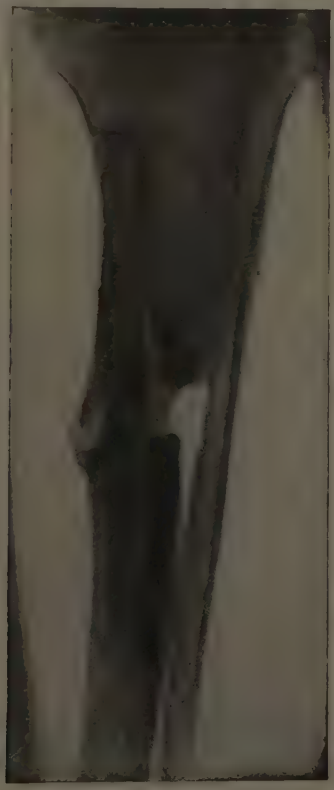


FIG. 295.—SKIAGRAM OF FRACTURED TIBIA AFTER AN INLAY CORTICAL GRAFT.

filled with a gauze swab and the graft is cut from the opposite leg. In this the periosteum is cut by a parallelogram 7 inches long and 1 inch wide and reflected inward. The infolded periosteum is covered by the larger templet plate which is nailed in its place and serves to protect

the periosteum from injury. The graft is cut in exactly the same way as the groove, the sides converging and the ends undercut. In order to free the graft a little piece at both ends must be first taken out in the manner shown in the diagram (Fig. 294). The graft is now hammered

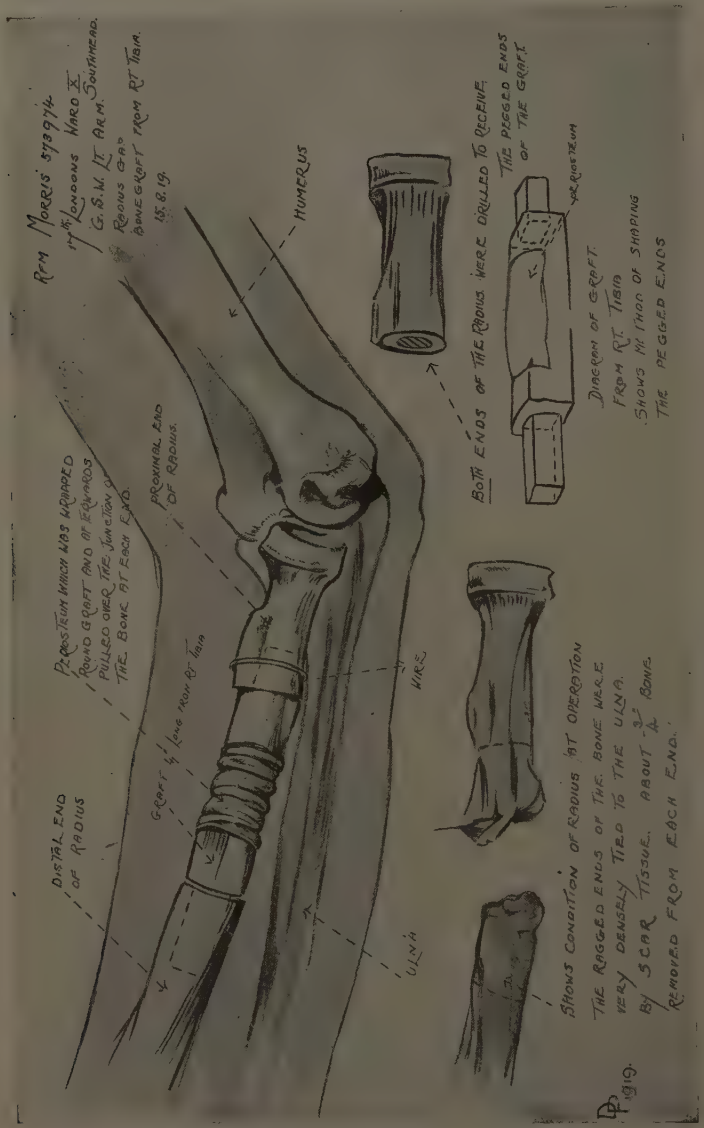

Rfm Morris 573914
11th Lancers Hard X
G.S.W. Lt Arm. Sowinhead.
Radius & Bone Graft from Rt Tibia.
15.8.19.
Humerus
Periosteum which was wrapped round graft and at ends pulled over the junction of the bone at each end.
Proximal End of Radius.
Graft 4" long from Rt Tibia
Distal End of Radius
Wire
Ulna
Both ends of the Radius were drilled to receive the pegged ends of the graft
Periosteum
Diagram of Graft from Rt Tibia shows method of shaping the pegged ends
Shows condition of Radius at operation the pegged ends of the bone were very densely tied to the Ulna. By scar tissue. About 1/2 Bone removed from each end.
Pigg.

Fig. 296.—Bone-grafting for a Gap Fracture of the Radius.

into the groove in the bed until its surface is flush with that of the original bone. In order to fit the under cut ends the fracture is distracted and then allowed to come together. In this way the graft is automatically kept in position without any sutures. The periosteum of

the graft is sewn all around to that raised from the bed. If there remains a dead space between the fragments from which scar has been excised this should be snugly filled by the bone cut to make the groove. The flap wound is sutured and the leg put up in plaster (Fig. 295).

Medullary Fixation of Grafts.—This operation is most useful in the case of a wide gap in the radius. The bed for the graft having been prepared by preliminary scar removal or replacement, the bone ends are

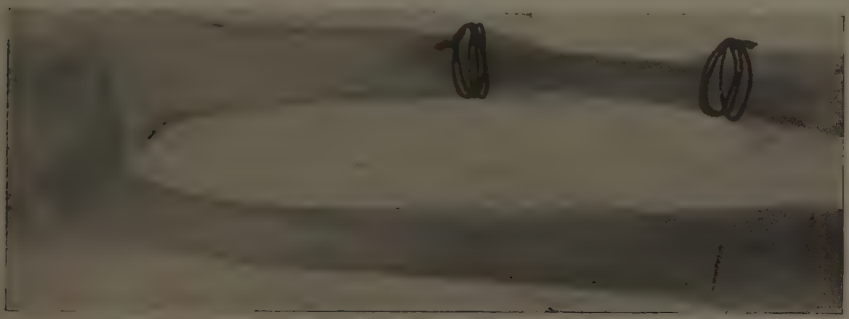


FIG. 297.—SAME CASE AS SHOWN IN FIG. 278 SIX MONTHS AFTER BONE-GRAFTING.
Note the bony union of graft to its bed, the dense strong graft, and the normal contour of the radius.

refreshed and drilled for 1 inch by that size twist drill which just bites upon firm bone. This is usually about $\frac{5}{16}$ inch in diameter. The graft is then prepared. It should be $1\frac{1}{2}$ inches longer than the gap it has to fill, when the latter is lengthened to its utmost by traction on the hand. The graft should be the full width of the shaft of the radius and should have attached to it an ample piece of periosteum, taking prac-

FIG. 298.—GAP FRACTURE OF RADIUS AFTER INSERTION OF A BONE-GRAFT.
Note the restoration of the curve of the radius and its correct position relative to the ulna. The wire is rarely necessary.

tically the whole width of periosteum from the anterior surface of the tibia. The graft should include the crest of the tibia if special strength is required. The wound in the donor's leg is sutured and the graft is then shaped. This is done by turning back the periosteum for $\frac{3}{4}$ inch at each end, and by means of the saw, file, and doweling tool shaping each end into a round peg to fit the size of the marrow cavity as measured by the drill by which the latter was bored (Fig. 296).

The graft is now fitted into the radius by driving one peg end into one fragment and placing the other peg into the other fragment either by splitting and subsequent wiring or by outward distraction. If the latter manœuvre is used the peg end should be reduced to about $\frac{1}{3}$ inch in length and a temporary wire suture be passed round the end of the radius, which prevents splitting. The ample periosteum of the graft is then brought round the graft itself (Figs. 297, 298) and sewn together and at each end the redundant membrane is sewn like a cuff over the junction line between the fragment and its bed (Fig. 299).

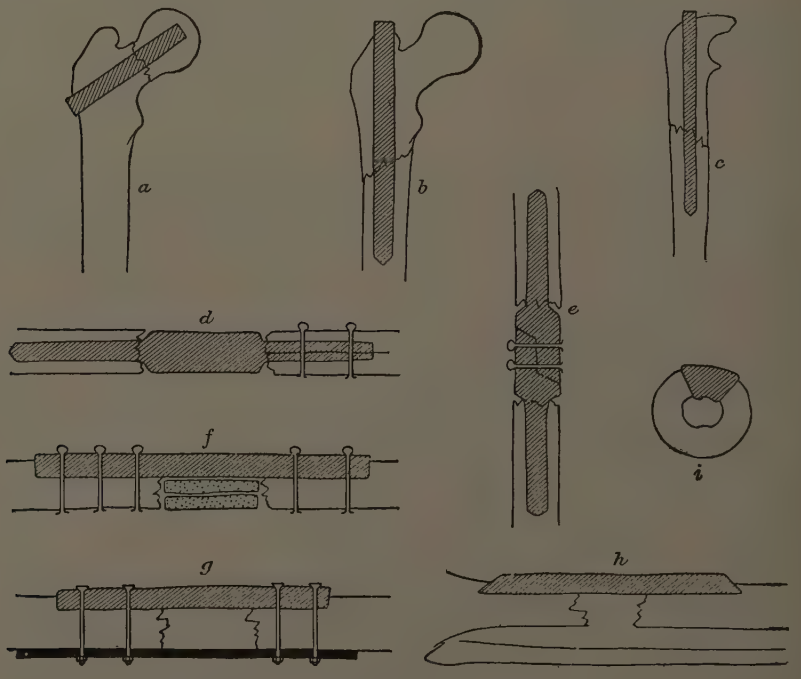


Fig. 299.—Showing Methods of Fixing and Fitting a Graft.

a, Graft driven into trochanter, neck, and head of femur; *b*, graft driven into medulla of upper third of femur from trochanter; *c*, graft driven into medulla of proximal part of ulna from olecranon; *d*, graft tightly fitted into both fragments of a fracture; at one end the shaft has been split for its reception, and then pinned together; *e*, graft tightly fitted into both fragments of a fracture; the graft has been cut by a fret-saw in a Z manner and pinned together afterward; *f*, graft fitted as a cortical strut and fixed by pins; the fragments marked by dots have been cut from the shaft and used to fill up the gap between the main ends of the bone; *g*, graft fitted as a cortical strut and bolted to a plate on the opposite side of the bone; *h*, inlay graft fitted and fixed without metallic sutures; *i*, section of the inlay graft, showing its wedge shape.

Bone-grafting for the Humerus and Femur.—In these bones where there is a real gap to be filled the operation is fraught with much difficulty, which attains its maximum in the case of the humerus. In either of these bones if the gap is not more than 2 or 3 inches we are convinced that it is much better to bring the ends together and to trust to one of the above-described methods of impaction or oblique junction. In the humerus where 4 or more inches have been lost the arm is usually much scarred, wasted, and badly covered by soft parts. In such a

case it is probably best to fix the graft into the upper fragment by driving it into the marrow cavity and to the lower by side-to-side apposition after cutting a groove in the bed.

The arm must be fixed in abduction by a plaster dressing which includes the trunk and the forearm in order to take off the weight of the limb from the graft. In the case of the femur the difficulty is not so much getting the graft to take, as that of making it strong enough to withstand any weight (Fig. 300). A cortical graft, such as that described for the tibia, should be applied to the outer surface, and the pieces of bone cut from the grooves in the bed to fill the remainder of the gap.

FIG. 300.—FRACTURE OF GRAFT USED IN THE TREATMENT OF A BROKEN FEMUR.
The graft was from the fibula and had firmly united to both fragments, but it broke just at the junction.

We have been *very disappointed* with the results of bone-grafting in the humerus and in the femur. Absorption and refracture of the graft are common, and only very occasionally do we find a real progressive development of the graft.

STIFF AND ANKYLOSED JOINTS

It is not our purpose in the present article to deal with the early phase of gunshot wounds of the joints except in regard to certain general principles.

In the early phases of the war, when thorough treatment of septic wounds was not understood nor was it possible to apply this treatment

at any early stage, a very large proportion of all surviving cases where the joints had been penetrated or shattered becamed crippled by ankylosis. The mortality of these wounds was at first so high that many were inclined to resort to somewhat desperate remedies. Early and extensive resection of the joints, especially of the elbow and knee, were seriously advocated, with the result that we now have the problem not only of the ankylosed joint, but the much more difficult one of the flail-joint to deal with.

It is impossible to deny that in some of these cases where several inches have been removed from the lower end of the humerus or femur, the limb may have been saved. But it is equally impossible to avoid a conviction that the limb might generally have been saved by less heroic measures.

We hold that three principles should govern the practice which concerns the early treatment of gunshot wounds of the large joints:

1. *Thorough treatment must be undertaken within twelve hours of wounding.*

2. *The treatment must include excision of the wounds with removal of infective material and infected tissues.*

This treatment consists in good *x*-ray examination to detect the presence of foreign bodies and the existence and extent of fractures. The wounds must be excised together with the track of the missile, as far as practicable without further injury to the joint. The cavity is copiously irrigated, foreign bodies and all loose bone which actually abuts upon the articular surfaces should be removed.

If débridement cannot be thoroughly carried out without further joint destruction then reliance must be placed upon the Carrel-Dakin treatment for maintaining sterilization.

3. *The utmost conservatism should be observed as regards large fragments of bone, particularly when these form an integral part of the shaft.*

It is quite unjustifiable, in our opinion, to cut through the shafts of the bone on either side of the injury with the idea of removing the damaged tissues *en bloc*. Such a procedure almost inevitably leads to a bad flail-joint.

If the joint is cleared of foreign bodies, dead tissue, detached fragments of bone, and placed at rest, then rapid and smooth healing will take place, while by a later operation the degree of movement may be increased by some of the procedures described below.

It is to be noted in this connection that the ball-and-socket joints, the shoulder and hip, allow of more radical early treatment than do the hinge-joints, the elbow and the knee, without the fear of producing unstable articulations.

On the Breaking Down of Periarticular Adhesions.—Stiffness due to adhesions of the lighter type have often to be broken down, and the question will arise, "How are we to diagnose those conditions improved by manipulation and those harmed by it?"

To assist in this diagnosis we will formulate certain rules which may help the surgeon:

(*a*) Pain on movement in every direction suggests a lesion in the joint or in parts intimately connected with it.

(*b*) Freedom of movement in one or more directions, but not in all, suggests a lesion of some group of structures outside the joint proper.

(*c*) A joint may be assumed to be free from arthritis when even one of its movements is complete.

(*d*) Traumatic arthritis follows an injury after an interval of free movement lasting usually over several days.

(*e*) Restricted movements due to adhesions arise very shortly after the occurrence of injury.

(*f*) Except when following serious injuries, adhesions restrict the movements of joints in one or more, but not in all directions.

A joint which is the seat of arthritis should not be moved until all inflammatory symptoms have subsided.

On passive movement a joint with fibrous adhesions conveys a characteristic sensation to the hands of the surgeon which differs, on the one hand, from muscular resistance associated with pain, and the abrupt blocking of movement caused by a bony obstruction on the other. The cessation of movement is definite and unmistakable, but it is not associated with pain unless the surgeon exerts a little force to put tension on the fibrous bands. If in any doubt whether there is disease of the osseous elements of the joint, an *x*-ray photograph will dissipate it.

On the Breaking Down of Adhesions.—It should be clearly understood that we are dealing here with the simpler forms of peri-articular adhesions—not those accompanied by destruction of joint surfaces, nor those where septic processes have involved the structures round the joint. These severe cases should be approached in quite another way, and are not suitable for so-called forcible manipulation.

Many tragedies have already occurred by not grasping this fact. It is fundamental and arresting. To give emphasis to this we submit the following rules:

1. Before breaking down adhesions exclude the presence of active arthritis.

2. In breaking down adhesions in stiffness following traumatic arthritis we must proceed very slowly, and if inflammatory reaction supervenes the manipulation should not be repeated.

3. Stiff joints following septic conditions within or immediately without the joint should not be submitted to forcible manipulation.

4. Adhesions are best broken down under complete anesthesia, and the joint should be put through its complete range of movement—otherwise a recurrence of stiffness may be expected.

5. Sudden jerking movements must be avoided because: (*a*) They are inefficient. (*b*) They cause unnecessary trauma. (*c*) They may break a bone instead of a fibrous band.

We will next consider the indications for breaking down adhesions, and separate this group from that in which the stiffness will recover without intervention. This may be done by formulating rules:

(*a*) Stiffness which gradually disappears as the joint is used may be safely left alone.

(*b*) If the increase of the range of movement in all or any one direction ceases to progress, intervention is called for.

Certain symptoms following manipulation and passive movements indicating injurious strain may be here formulated:

(*a*) If pain occurs after manipulation and is of *short* duration, the movements may be safely continued.

(*b*) If pain persists for lengthy periods after manipulation, rest is indicated.

(*c*) If the increased range of movement is maintained after manipulation, further movement can be safely prescribed.

(*d*) If in spite of movements even in the absence of great pain the range is continuously diminishing, rest is indicated.

(*e*) The duration of pain, when tissues are relaxed, rather than its intensity, should be our clinical guide.

(*f*) In breaking down adhesions and in subsequent manipulations, the joint should be put through its various movements only once. The oft-repeated, pump-handle movements applied at each sitting are never useful and often start inflammatory symptoms.

(*g*) Unlimited voluntary movements can be safely allowed and should always be encouraged. They are not followed by obstructive reaction.

Stiffness Due to the Contraction of Scar Tissue.—The war has supplied us with numerous instances of joints fixed in deformities due to the contraction of scar tissue. This most frequently happens in the shoulder, elbow, wrist, hand, and knee. The malposition can be avoided by correct initial treatment, whatever the extent of the destructive process.

When the scar is situated, say, in front of the wrist, at the back of the knee, or the flexure of the elbow, there is a great tendency for the scar to go on contracting until the limb is fixed in a useless flexed position. Owing to the contraction of the scar the blood-vessels cannot expand freely, and the whole area becomes dense, white, and anemic.

In the **first stage**—*i. e.*, while healing by granulation is taking place—the region of the wound must be left very much at rest. Fractures should be placed in the best position, torn tissues brought together as well as possible, and then left for the new repair blood-vessels to grow between fragments. These vessels grow in the plastic exudate, therefore any rough handling, injudicious massage, or movement will only tear them and obstruct healing. The wound must be treated on modern lines, free exit given to all discharges in septic cases so that the tissues may be as little sodden in poisonous toxins as possible, and be freely nourished and fortified by the food elements and antibodies in the body fluids.

This is the stage in which the surgeon must decide as to the position in which he should place the limb. This should be in the position opposed to the direction in which the scar contracts. The limb should retain this position until repair is well established.

In the **second stage**—*i. e.*, after healing has taken place but the scar is still vascular—passive movement is apt to tear newly formed tissues, cause bleeding, and increased organization of scar tissues. On the other hand, it is now possible to change the position of the limb gradually. It is during the end of this stage when the tissues are becoming matured that the contractile element is at work. Therefore if the limb has not already been put up in the position opposed to deformity this should be done as soon as possible.

The following rules should be observed:

1. The strong muscles in the axillary fold when torn by shrapnel must not be allowed to heal with a short stiff scar. Therefore the arm should be abducted.

2. Wounds in the flexure of the elbow should be treated with the elbow extended.

3. Burns and septic wounds of the front of the wrist and the palm of the hand must be treated in dorsiflexion.

4. For wounds in the flexure of the hip the thigh should be in a line with the body, slightly abducted.

5. In wounds of the back of the thigh the knee should be kept straight.

6. The foot must always be kept at right angles to the leg.

Third Stage.—Healing is complete and the scar is almost avascular. When wounds have already reached the contracting or fully contracted stage they are often even then amenable to mechanical treatment. As early as 1884 a girl of fifteen was brought to one of us with her wrist acutely palmar flexed due to the contraction of scar tissue following a burn experienced ten years earlier. She would not submit to a pedicle-skin-flap operation, so during a period lasting some weeks we gradually brought her wrist into dorsal flexion, kept it in that position for many months, with the result that no recurrence of contraction took place and an excellent range of movement resulted. This experience has served us well in many subsequent problems where the stretching of the scar has been involved. The stretching must be continuous. The correction is not so much due to the actual yielding of the scar as to the stretching of the healthy skin which surrounds it. Fully matured fibrous tissue has no more tendency to contract than any other tissue, but as it takes a long time to mature, the extension must be long continued. Remember also that excessive granulation favors firm contraction.

Operative Treatment of Scars.—Operation may be needed in any of the following conditions:

1. Painful scar. 2. Scar bound down to muscle. 3. A firm scar involving the elbow or wrist.

Scars giving rise to stiffness of joints are sometimes extremely hypersensitive. They should be excised and, if possible, the cut edges should be submitted to immediate suture. If this is impossible, a plastic readjustment should be done. The wound should not be allowed to heal by granulation tissue. The excision should be complete.

When the scar is bound down to muscle the dissection may be quite extensive; then it is very necessary to proceed with caution. Nerve trunks may have to be exposed to avoid accident, for to be successful the completest possible removal of the cicatricial tissue is called for. In a large proportion of cases cicatrices resulting from gunshot wounds can be removed, leaving sufficient skin for suture. After operation the malposition of the joint should be quite overcome and the position maintained until the wound is healed.

Firm scars of an extensive character may involve the wrist in dorsiflexion or plantar flexion and the elbow in flexion. After the removal of these it is possible that no skin is available to cover the wound. It is best then to fix the edges of the wound of the wrist or the elbow to a flap dissected from another part of the body. The elbow, for instance, if it cannot be straightened can be attached to the breast.

The edge of the wound following removal of a scar from the dorsum of the wrist can be attached to the abdomen by means of a cuff incision.

When the operation has been performed upon the front of the wrist a very comfortable position is to place the hand just behind the trochanter.

During and after operation certain points must be noted:

(*a*) Excision must be complete, leaving healthy flap for fixation. The flap should contain its fat and cellular tissue. (*b*) No tension must be allowed on the flaps. [*Vide* also Schamberg's Chapter on the Skin. —W. W. K.]

The Treatment of Fibrous Ankylosis of a Graver Type.—If a joint has been kept immobilized for many months for the treatment of a fracture of an adjacent bone, and especially when there has been a chronic septic inflammation in the limb, a severe grade of fibrous ankylosis will result due to an adhesion of the muscles and tendons to the shaft and articular ends of the bones.

In the majority of cases it is worse than useless to attempt to treat such cases by forced movement, with or without an anesthetic.

Dense adhesions and masses of scar tissue of great strength are the cause of such conditions and are associated generally with weak atrophic bones and weakly united fractures. Force suddenly applied to mobilize such joints can only tear muscles or scars or, more likely, will break the bone or tear off bony processes to which the muscles are attached.

There are two ways in which we can safely attempt to bring about mobilization in this class of case:

(*a*) Gradual flexion on a splint in successive short stages. (*b*) Forcing in successive stages under anesthesia with rest in splints during the intervals.

This method of attack is suited to the stiffness of prolonged immobilization, traumatic arthritis, and cases in which suppuration has occurred about the joint.

We have often pointed out that joints which will not yield at all to manipulation under an anesthetic will often do so when subjected to the force applied by gravity assisted by a bandage. Furthermore, in

a joint, such as the elbow, a flexion which cannot be brought about in safety by one manipulation can often be achieved by continuous stretching of the shortened structures. We will illustrate this, taking the elbow and knee as examples, because a most important and practical principle is involved.

It is desired in an old arthritis or in old dislocation backward of the forearm to bring the elbow from an obtuse to an acute angle. Under an anesthetic the surgeon, after considerable efforts, succeeds in gaining 20 degrees of flexion. He now feels that any further attempt will result in fracture, as further movement is firmly obstructed. The arm is fixed by a sling in this position of the greatest possible flexion, and in a few days the surgeon makes another effort. He will then find that he can with but little effort bring about further flexion, which would have been quite impossible in spite of greater effort on the first occasion. In a few days another trial may have to be made to secure the full extent of the flexion needed. The ligamentous structures at the back of the elbow slowly yield under strain. This is true of shortened ligaments as well as of scars.

The same principle will obtain in the case of the knee, but in our attempt to flex a straight knee we have the advantage of the action of gravity. If the knee admits of, say, 15 degrees of flexion, a long posterior splint is applied set at an angle of 15 degrees more. The limb is bandaged to this, and when the extra 15 degrees have been gained, the knee is kept at rest on the splint for a few days in order to relieve the strained tissues. The bandage is then removed from below the knee, which is allowed voluntary movement in the direction of full extension. When this has been secured the splint is bent another 15 degrees, and the procedure is repeated. This is continued until sufficient flexion is obtained to enable the joint to be more vigorously exercised, first by active and then by passive movements.

True Ankylosis

The term "*true* ankylosis" must be confined to conditions where the joint surfaces have been involved.

A further most useful classification introduced by Thomas is that of "sound" and "unsound." The term "'sound' ankylosis" implies the absence of active disease. In a sound ankylosis the flexion angle will not be altered by use. In "unsound" ankylosis the deformity imperceptibly increases until its extreme limit is reached. The increase in the angle of deformity does not imply an increase in the range of mobility, for an increase in the range of mobility denotes a recovered joint. An unsound ankylosis should be treated by absolute fixation. It always denotes active disease, although it may be almost or wholly painless. An unsound ankylosis can usually be corrected by mechanical means. After fixation, when the inflammatory element has been overcome, an unsound ankylosis becomes a sound one. An unsound ankylosis has to be treated with a view of its becoming a true ankylosis. We will now discuss the position of election for ankylosed limbs.

Shoulder-joint.—The arm should be abducted to about 60 degrees from the side. The elbow-joint should be slightly in front of the coronal plane of the body (Fig. 301), so that when the elbow is at right angles and the forearm supinated the palm of the hand is toward the face. The arm is placed in this position while the scapula retains its normal position of rest. In this position the hand can be easily made to reach the mouth by merely bending the elbow. Again, the humerus being fixed at this angle to the scapula the arm can be lifted a considerable height by scapular action; pockets can be reached, a glass of water can be carried to the mouth without spilling its contents,

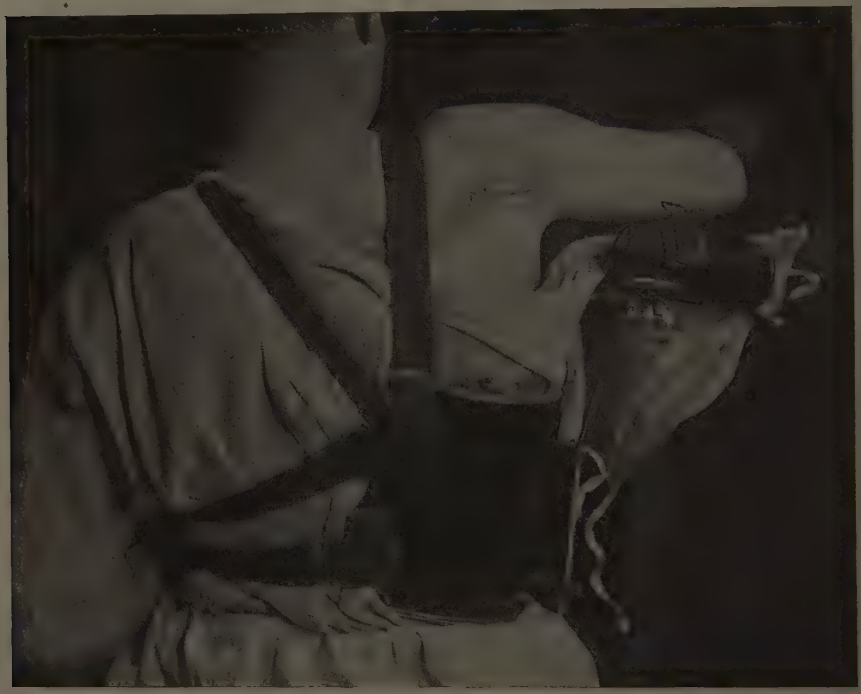


FIG. 301.—SHOULDER ABDUCTION SPLINT.
Note that after wearing this splint the patient is able himself to perform a further degree of voluntary abduction. (Naughton Dunn's case.)

and various essential acts can be performed with ease. If ankylosis is feared *the arm should never be kept to the side*, or the result will be functionally bad—not only will it be difficult to reach many parts of the body, but difficult to reach across the table or to perform many simple movements constantly recurring in every-day life. In discussing the question of fixation of flail shoulder we will deal further with this matter (Fig. 305).

The Elbow-joint.—Before deciding the angle at which the elbow-joint should be fixed the calling of the patient should be considered and a consultation held with him in order to obtain his views. The greater number of men prefer an ankylosis at about a right angle. If

both elbows are ankylosed it is best to fix one slightly less and the other slightly more than a right angle. The ankylosis commonly met with at about 130 degrees is functionally bad.

This position at a right angle enables the patient to move his hand to his mouth, button his clothes, brush his hair, and reach across a

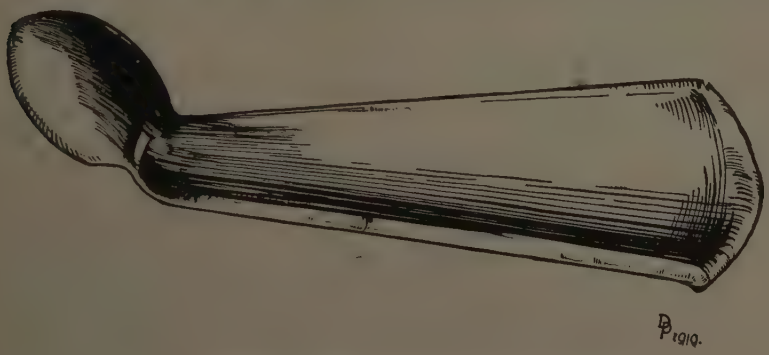


FIG. 302.—SIMPLE PATTERN OF WRIST DORSIFLEXION SPLINT.

table. At an angle considerably less than 90 degrees it is more easy to get the hand to the mouth and to various parts of the head, but limitations in other directions more than counterbalance these advantages.

Forearm.—The forearm should never be fixed in a position of pronation. If a condition—*e. g.*, great comminution of the upper or

FIG. 303.—DORSIFLEXION SPLINT WRONGLY APPLIED. THE SPLINT HAS SLIPPED DOWN SO THAT THE METACARPOPHALANGEAL JOINTS ARE HYPEREXTENDED. (From McMurray.)

lower ends of the radius and ulna—exists in which ankylosis is likely, then the forearm should be fixed midway between pronation and supination. If the condition will not lead to ankylosis, then it is best to ensure full supination from the outset, because pronation is readily regained, while supination of a prone arm is most difficult to restore.

Wrist-joint.—All injuries of the wrist-joint should be treated with the wrist dorsiflexed. The common deformity which results in an arthritic wrist where no splint is applied, or where even a straight splint is applied, is that of palmar flexion, and the position is a very serious disability while it lasts. It is so serious that when a wrist is brought to us in this condition with true ankylosis we invariably operate upon it in order to fix the wrist in dorsiflexion.

The reason we advocate dorsiflexion is primarily due to the fact that in this position the grip of the fingers is strengthened, although even from the esthetic point of view dorsiflexion is indicated. A palmar flexed wrist is always an eyesore. Care must be taken that the dorsiflexion splint is not allowed to slip downward, otherwise the metacarpo-

Fig. 304.—Wrist Dorsiflexion Splint Correctly Applied. (After McMurray.)

phalangeal joints will be hyperextended, a condition which may give rise to serious disability (Figs. 302–304).

Hip-joint.—Ankylosis should be secured in a position of very slight abduction with thigh extended and with very slight outward rotation. The common deformity in ankylosis of the hip is flexion, adduction, and internal rotation, which is the characteristic position in which we find the untreated tuberculous hip-joint. It is accompanied by an ugly limp and a certain degree of lumbar lordosis. Adduction deformity brings the limb too near the middle line, interferes with the normal position of the sound limb on walking, and by involving the sound limb in abduction it interferes with a free swinging gait.

If the hip-joint be ankylosed in the fully extended position, lordosis and the consequent trouble from backache are avoided, and there is

freer pelvic movement in walking if the thigh is slightly abducted. The limb should also be very slightly rotated outward to avoid the unpleasant lift of the pelvis as the patient rises on his toes when walking. Walking is easier if the toes are not pointed straight forward.

Knee.—This joint should be fixed in an extended position. In recommending this position we know we are at variance with certain distinguished American colleagues who prefer an angle of 135 degrees of extension. Good reasons may be given in favor of slight flexion from the point of view of elegance in repose and that of ease in mounting stairs. Due weight should be given to these points, but in war injuries the straight position obviates many risks. Ankylosis, as we know, is not always bony, and if not, the tendency is for the flexion angle to increase by exercise—unsound ankylosis. The incidence of body weight on a slightly bent knee, unless the ankylosis is sound and bony, will increase the flexion. The position, therefore, is mechanically a weak one for carrying the body weight. Even when bone is forming its complete consolidation is sometimes a slow process, and if the surgeon places such a consolidating knee in a flexed position the degree of ultimate flexion is often greater than he would wish. The advantage of increased strength and stability ensured by an extended joint will outweigh all other considerations. In taking a wedge from a knee with bony ankylosis in a flexed position where fixation in any position becomes easy and bony fixation certain, it is an open question whether slight flexion may not be indicated.

Ankle.—At the beginning of the war we advised surgeons to ankylose the ankle-joint at a right angle. After examining a large number of cases we now agree that where ankylosis has occurred at the tarsus or at the joints of the toes, the foot should be ankylosed a few degrees more acutely than a right angle. This enables the patient to walk with the minimum of strain upon the front part of the foot. The ankle should be so fixed that neither valgus nor varus should be evident. Slightly varoid deformity is preferable to the slightly valgoid one.

The consideration of true or bony ankylosis resolves itself into a primary distinction between ankylosis in a good position and a bad position, and a further discussion as to the indications for and methods of treatment. It is but seldom that ankylosis in good functional position requires treatment, especially when it follows upon war injuries, in which a serious danger of latent sepsis always lurks.

True Ankylosis of the Shoulder-joint.—If a shoulder is *ankylosed in the correct position* few surgeons would wish to alter it. In our own practice we are content with this result, and on the few occasions where we have operated by procuring an arthroplasty, there have been special circumstances which have influenced us. One of these circumstances has been a fixed scapula, and sometimes when pressure has been brought to bear upon us and we have found a limited synostosis of the joint, with no bony outgrowth and a clearly defined head. In spite of exceptions of this type we would emphasize our belief that a shoulder ankylosed in good position produces the best functional result.

True Ankylosis in a Bad Position.—There are two operative procedures:

(*a*) Osteotomy. (*b*) Resection.

Osteotomy through the neck of the humerus is that which is usually demanded. It is as successful in improving function as is osteotomy of the upper part of the femur. An incision is made through the anterior fibers of the deltoid and a section through the bone is effected by a chisel. The operation should be conducted with care, a sand-bag being placed behind the shoulder. The arm should be fixed for a few weeks in the position of election. A range of scapular movement may be secured which allows of easy feeding, abduction to well beyond the right angle, the hand can reach the pockets, and, with a little knack, the collar can be fastened behind. The arm should not be rotated too far outward. This operation must not be performed in any case where the shoulder cannot be shrugged or where the rotation of the scapula is interfered with.

Arthroplasty, or excision of the shoulder, is sometimes a success and often a failure. It is indicated where the scapula is fixed and where a good deltoid is found. It is contraindicated where a large mass of bone is collected in the axilla. The best routine incision is the anterior one between the deltoid and the pectoralis major, curved upward and backward over the shoulder in order to ensure an exposure of the deltoid and acromion. A flap of subcutaneous tissue and deep fascia is turned downward and left hanging by a pedicle. The flap of fascia is now passed round the head of the humerus and the parts stitched. The arm should be fixed on an abduction splint in the position of right-angled abduction, and massage with voluntary movement from the splint started early. A useful simplification of this operation has been made by Stiles, who, instead of using a fascial flap, rubs Horsley's wax into the rounded end of the humeral shaft. If in addition to the ankylosed shoulder stiffness of the arm and fingers is found, these complications should be treated first of all before any attack is made upon the shoulder-joint.

The cases where operations to obtain mobility may be considered are:

(*a*) Where the deltoid is acting well, but the elevators of the scapula are destroyed.

(*b*) Where the contour of the head of the humerus is not obliterated.

(*c*) Where mobility at the expense of strength is desired.

(*d*) Where the glenoid and the acromion are absent.

The question of mobility should not be considered:

(*a*) Where the deltoid or where the muscles attached to the tuberosities are destroyed.

(*b*) Where a mass of bone is present in the axilla due to comminuted fracture.

(*c*) Where strength is preferred to mobility.

(*d*) Where an ankylosis in good position exists.

An arthroplasty of the shoulder is not indicated where the muscles governing scapular movements do not act.

From our observation of cases examined at the various centers we repeat that for a working man an ankylosis in good position provides the surest functional success.

Correction of Faulty Ankylosis of the Shoulder.—This is frequently indicated, as so many shoulders have been allowed to ankylose in adduction with a certain degree of internal rotation. Correction can usually be effected by a simple osteotomy.

Osteotomy of the humerus to correct malposition of the shoulder should only be performed where bony ankylosis is present. It never should be done if ankylosis is fibrous. When osteotomy has been per-

FIG. 305.—DIAGRAM OF ARTHRODESIS OF SHOULDER-JOINT.
The two wires shown can be removed at a later date without exposing the joint.

formed in the presence of fibrous ankylosis the weight of the arm has always allowed the deformity to recur.

If there is a great deal of thickening at the upper end of the humerus it may be necessary to remove a wedge of bone with its base outward. As a rule, however, a simple osteotomy suffices, and, where possible, it is best to make an osteotomy through healthy bone if that can be effected sufficiently high up. The incision can be made anteriorly. Although the deltoid is not of much importance where ankylosis exists, it is not advisable to interfere with the circumflex nerve by making the incision on the outer side.

After the operation the arm should be fixed and maintained at the appropriate angle, which we have already discussed. A bed can then be prepared for the acromion which thus becomes fixed to the humerus. In this way we can provide for a sufficiently extensive callous exudation to minimize any risks of failure.

A more precise arthrodesis of the shoulder can be effected in the following manner (Fig. 305): After the usual exposure of the joint the under surface of the acromion and the face of the glenoid are chiseled to present rough raw surfaces at right angles to one another. The arm is then placed in the appropriate position and lines are marked on the head of the humerus parallel to the new surface of the acromion and glenoid. The humerus is dislocated and the head is then sawn by two saw-cuts along the line drawn. It is replaced in its prepared socket and then fixed by two loops of stout, soft, iron wire, or kangaroo tendon, one of which ties it up to the acromion and the other ties it against the glenoid. The actual tightening and tying of these bands should be left to the last stage of the operation after the main wound has been sutured. The ends of the acromial wire are brought out through the skin over the tip of the shoulder, those of the glenoid wire through the deltoid. If wires are used they can be removed at a later date if necessary, without interfering with the main wound.

True Ankylosis of the Elbow.—Treatment of this condition will consist of: (*a*) Fixation in good position. (*b*) Pseudarthrosis or excision.

The relative advantages of operation for mobility or fixation are still open to discussion. It is only after frank explanation with our patient as to the possibilities and danger that we can come to a definite conclusion as to values. The surgeon is often asked to stiffen a mobile weak elbow and to mobilize a strong fixed one. Function in the one case will depend on strength; in the other, on mobility. Given the assurance of free movement with full strength after a pseudarthrosis there can be no question of its superiority. A perfect result, however, is rarely seen. In a large proportion of cases a varying degree of lateral mobility is found, and a certain loss of strength which prevents the lifting of heavy loads.

Men who do not require the arm for hard manual work will be willing to sacrifice strength for mobility. The artisan who has an ankylosed arm in a good position will prefer it to a weak mobile one. We will, therefore, point out the type of case where pseudarthrosis is likely to succeed, and that in which it is best to recommend fixation.

Mobility may be indicated where

An ankylosed elbow is fixed in a bad position.
A short fibrous ankylosis exists with pain.
The articular ends of the bones are defined.
An ankylosis has occurred in each elbow.
The flexor and extensor muscles act.
Ankylosis of shoulder or wrist coexist.

Fixation is usually indicated where

The ankylosis is in good position.

The muscles governing the elbow are extensively damaged.

The ends of bone are comminuted with callous exudates.

The joint is surrounded with scar tissue.

The opposite arm has been amputated.

Correction of Faulty Ankylosis by Operation.—This is best done by an open operation. A posterior incision is made 3 or 4 inches in length in the vertical plane, and a subperiosteal osteotomy is performed. There is no necessity to remove a wedge. If the joint is comminuted, an osteotomy should be planned through the lower part of the humerus just above the joint. The joint is then fixed for six weeks.

In the absence of pronation and supination, the head of the radius should be removed and the periosteum should be sewn over the divided end. This operation should not be done at the same time as the osteotomy, otherwise the necessary passive and active movements, so essential to success, cannot be proceeded with. Recurrence of stiffness occurs sometimes after removal of the head of the radius. This is usually the result of callous exudation. To minimize this risk, the head of radius should be removed very freely, and Horsley's wax, as recommended by Stiles, should be rubbed into the cut end of the bone; or the periosteum should be stitched over the bone; or fascia should be wrapped around it. In addition, the end of the bone should be rubbed smooth.

Excision or Pseudarthrosis.—It will be in the memory of many surgeons that in the days when the usual classical excision of the elbow was exclusively practised very excellent results were often obtained. When examined many years afterward these cases gave evidence of considerable power and stability. Muscular control became much more marked with time. We can recall a great number of excisions in the adult, and the successful cases have always been those where sufficiently free removal of bone has been practised. The incision to be adopted is the posterior one. It should be about 4 inches in length with its center opposite the prominent tip of the olecranon. The points upon which stress should be laid are the preservation of the insertion of the triceps and its expansions into the deep fascia of the forearm over the anconeus; the preservation of the lateral ligaments; the clearing away of detached periosteum; and where ankylosis is bony, to make a preliminary section of the bone at the level of the joint with an osteotome or saw. The most useful line of section in the forearm should ensure the removal of the greater and lesser sigmoid cavities with the olecranon, and the radius should be removed just above the insertion of the biceps. The section of the humerus should be above the level of the epicondyle on the outer side and through the highest part of the epitrochlea on the inner side. If less is removed, ankylosis is almost certain to result. When the arm is extended there should be an interval of $1\frac{1}{2}$ inches. To prevent partial dislocation forward it is advisable to make the section through the bone a curved one, especially in the case of the olecranon.

If these points are remembered very excellent results will follow the operation of excision. The approach to the joint is not a matter of real importance, but unless the surgeon has had a considerable experience of excision the posterior vertical is more simple than the lateral (Kocher).

The after-treatment is important. The arm should be kept absolutely fixed at right angles until the stitches are removed, and then very gently flexed to an acute angle once a day for a further fortnight. At the end of that time the wrist is slung by a halter and is lowered by degrees to an angle of 120 degrees of extension, the patient being allowed active movements. At night it is kept flexed to 60 degrees of extension, and released in the morning. This prevents strain of the brachialis anticus and biceps and should be continued for some weeks.

Certain modifications may be made in the operation. They have been suggested in order to overcome the two cardinal difficulties, viz.: recurrence of ankylosis on the one hand, and a weak flail-like joint on the other. Hitherto the only safeguard against recurrence of ankylosis has been the wide removal of bone, and it is just this step which gives rise to the formation of a flail-joint.

To prevent adhesion of the new bone surfaces to one another a free fat transplantation is made, the fat mass being taken from the patient's buttock and being of a generous size so as fully to fill the space left in the new joint. To prevent a weak flail-joint the olecranon and both epicondyles are preserved. Through the usual posterior incision the lower end of the humerus is exposed and both epicondyles are chiseled off and left attached to the soft parts. This ensures the preservation of the lateral ligaments. The lower end of the humeral shaft is cut off and shaped like a saddle by means of a file, concave from side to side and convex from before backward. The great sigmoid cavity of the ulna is similarly shaped, but concave in its long axis and convex in its transverse.

Stiff and Ankylosed Radiohumeral Joint.—The position of the forearm where this joint is fixed is usually one of pronation. The ankylosis may be due to:

(*a*) General arthritis of the elbow-joint.

(*b*) Comminuted or simple fracture of head or neck of radius.

(*c*) Contractions due to scar tissue.

(*d*) Synostosis of the superior radio-ulnar joint.

If the elbow-joint is ankylosed in good position, and the power of pronation and supination is absent, removal of the head and neck of the radius often partially, sometimes wholly, restores the function. It is necessary to remove sufficient bone to enable the movement to be easily performed on the operating table. The operation is destined to failure unless this can be easily done. The cut end of the bone should be rubbed smooth to lessen callous exudate and Horsley's wax applied. The arm should be fixed in supination for about ten days, and then passive movements gently performed.

The same treatment should be adopted in stiffness the result of

fracture. Care should be taken to remove all pieces of bone and to dissect away any flakes of periosteum. The incision is made on the posterior aspect of the radius.

Where the ankylosis is due to scar tissue, operation is usually not so successful, as it is frequently quite impossible to dissect away all scar tissue. An attempt, however, should be made to do this, and if at the time of operation one secures an easy range of movement a living flap of fat can be pushed round the radial neck.

Synostosis of the superior radio-ulnar joint is common after gunshot injuries. If the injury is above the tuberosity, it is necessary to remove the head and neck of the radius, and completely ablate all bony union between this bone and the ulna. The dissection must be free and not subperiosteal, or ankylosis will recur. The elbow should be fixed in extreme supination for a few days, alternating with complete pronation for a few days. Active movements must be practised.

The Wrist-joint.—Ankylosis of this joint may be due to:

(*a*) Prolonged immobilization.

(*b*) To the contracture of scar.

(*c*) The shortening of muscles.

(*d*) Bony block due to fracture and dislocation.

(*e*) Synostosis due to septic arthritis.

Injudicious splinting has been the cause of a large number of stiff wrists, and with the disability to the wrist must be added an almost certain obstinate stiffness of the fingers. To make matters worse, the stiffness of the wrist usually occurs in a faulty position, which adds greatly to the work of the surgeon. The arm has either been slung by the wrist, which becomes palmar flexed, or a straight splint has been applied which overextends the fingers and palmar flexes the wrist. In other instances a long cock-up splint is applied which slips upward, and the fingers are dorsiflexed instead of the wrist (Fig. 306). A long "cock-up" or dorsiflexion splint can be worn harmlessly for months in the case of children. This is not so, however, in the case of the adult. The palmar portion of the long "cock-up" should not be straight and flat, as is so general, and it should be provided with a thumb-piece. The position of rest for the hand is that which it assumes when it holds a large tumbler: the wrist extended about 45 degrees, the metacarpals and interphalangeal about 30 degrees, the thumb abducted and slightly approaching the palm. In this position all the muscles of the hand are relaxed. It is, therefore, very important to remember this in order to avoid paralyzing the muscles and stiffening the joint.

Our first duty in dealing with the stiffness of the wrist is to dorsiflex it. This may be done gradually on a long, properly shaped dorsiflexion splint, or under an anesthetic, when often great force is needed. A short dorsiflexion splint (Fig. 302) should then be applied, which, while maintaining the wrist in a correct position, leaves the metacarpal and interphalangeal joints free. If such force has been needed the splint will be left in position for ten days or a fortnight—the fingers being very gently moved and massaged. Then the splint should be removed

daily, the wrist exercised, and the splint readjusted until the deformity shows no tendency to recur.

Stiffness of the wrist due to contraction of the skin or the deeper tissues is treated on the same principle as that adopted where the contraction is due to prolonged immobilization. But the dorsiflexion must be maintained for a considerable period, more especially if the skin is at fault. The scar in time by drawing upon healthy skin under tension becomes so loose and relaxed that recurrence of deformity does not take place.

Stiffness due to the contraction of tendons, the result of injury to muscle, is very frequent, and it results in a condition often indistinguishable from Volkmann's ischemic palsy. This deformity presents a

Fig. 306.—Hand with Contracted Fingers After a Median and Ulnar Nerve Injury.

flexion of the wrist, hyperextension of the metacarpophalangeal and flexion of the phalangeal joints. Any attempt to dorsiflex the wrist results in further contraction of the fingers. This condition should be treated as follows:

(*a*) An assistant passively flexes the wrist to allow the fingers to extend, and each finger is separately strapped to a little gutter splint so that they cannot curl up.

(*b*) A day or two later, or in milder cases at the same sitting, the metacarpophalangeal range is stretched, and the palm and splinted fingers are bandaged to a flat metal splint—the wrist meanwhile being fully palmar flexed.

(*c*) The wrist is now from day to day extended a little and fixed.

This is continued until the wrist is dorsiflexed. The hyperextension of wrist and fingers is maintained for some time in obedience to the principles laid down concerning the extension of scars, massage being systematically practised. By this simple procedure the surgeon does much more than any operation would effect. He stretches all the scar tissues in the direct order of their tension. The muscles, infiltrated with fibrous tissue, are really the seat of a diffuse scar, and the effect of continuously stretching them releases the pressure upon the vessels.

Bony Block Due to Fracture and Dislocation

The cases of fracture and fracture-dislocation occurring in military surgery bear but little resemblance to those of civil life. They are usually accompanied by laceration and comminution, which add to their complexity. Every case of malposition should be corrected. The wrist should never be allowed to remain palmar flexed, and no excision of bone should be attempted unless we have a reasonable assurance of improved function. If masses of bone or angular splinters interfere with the function of joint or tendon they should be removed. If in an old compound dislocation attempts at dorsiflexion increase the dangers of pressure upon soft structures, bone should be removed, and an ankylosis in good position be secured. Very rarely indeed is a pseudarthrosis or excision called for.

Before performing any operation which involves keeping the wrist at rest, the fingers should be made as mobile as possible.

Bony Ankylosis.—If the wrist-joint is in good position, it should be allowed to remain so without operation. If the ankylosis is faulty, a wedge exsection should be performed, and the joint placed in dorsiflexion. Ankylosis of the wrist may occur with or without loss of pronation and supination. It may be confined to the radiocarpal joint, or be combined with the lower radio-ulnar. If synostosis has occurred at the radio-ulnar joint, movements may be regained by removal of a portion of the lower third of the ulna, as recommended by Baldwin, of San Francisco.

Stiff Fingers

It is a matter of common experience that the deformed stiff fingers, which often follow gunshot wounds of the arm, are extremely crippling and also very difficult to treat successfully by simple massage and movements. There is no deformity which, from its frequent occurrence and its functional importance, it is more desirable to cure.

The cause of stiff or contracted fingers is one of the following:

1. Nerve injury, especially of the ulnar and median nerves. 2. Septic inflammation in the forearm or hand. 3. Adhesion of scars to the tendons and of tendons to their sheaths. 4. Ischemic contraction of the muscles and tendons. 5. Long splint immobilization.

The treatment of cut or adherent tendons and of adherent scars must follow ordinary principles.

It is a wise rule to proceed by gradual stages rather than to attempt full operative correction at one sitting. Thus adherent cutaneous scars

should first be dissected out or replaced by new skin. Then adherent or divided tendons should be restored at a second operation. There are two devices which are worth a trial. The one is the replacement of gaps in the extensor tendons by strips of fascia lata. The other is the provision of a new sheath for a damaged or adherent tendon by means of a length of the saphenous vein.

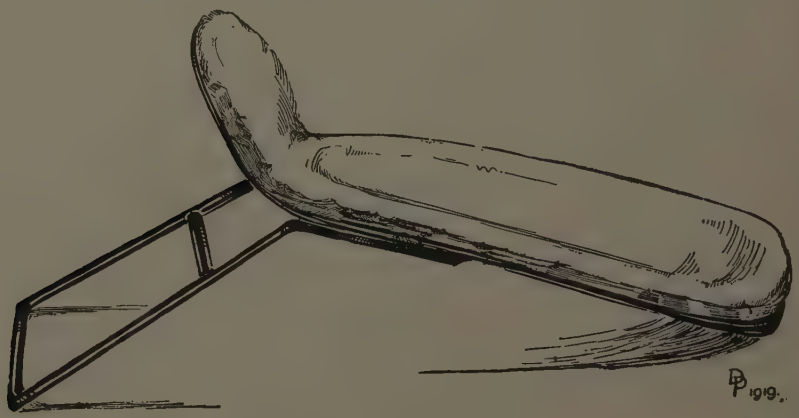


FIG. 307.—VERRALL'S SPLINT.

When, however, the scars have been removed and the tendons are intact, the problem of the stiff fingers may still remain for solution.

Forcible movement of such stiff fingers is very disappointing even with the addition of fixation either in extreme extension or extreme flexion.

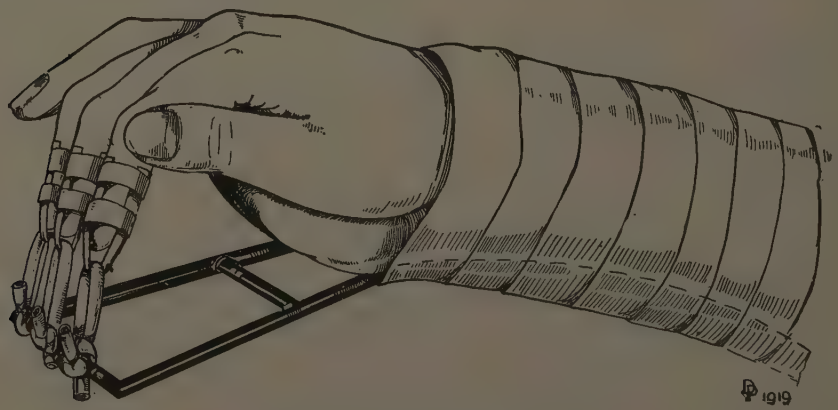


FIG. 308.—VERRALL'S SPLINT APPLIED.

The real clue to success consists in the combination of axial traction with gradual flexion or extension.

In certain very severe cases where there is hyperextension at the metacarpophalangeal joints a preliminary fasciotomy or capsulotomy of these joints will greatly expedite the recovery. A small tenotome is

passed underneath the extensor tendons and the dorsal and lateral parts of the capsule of the joints is divided. Traction is made on each finger from an adhesive plaster loop attached to the terminal phalanx. A tape or elastic is tied to the finger and attached to a metal bar fixed to a short cock-up splint. This splint with the bar attached was devised by Verrall and has been adopted very widely, with excellent results (Fig. 307). The cock-up part of the splint secures the wrist in dorsiflexion, while the traction on the fingers, being both distal and toward the palm of the hand, gradually produces flexion of the digits. A second bar nearer to the wrist is provided on the splint and serves as a point of attachment for the finger tapes when full flexion has to be obtained. The splint itself may be secured at first by plaster of Paris to the hand, but from the very outset the fingers are untied each day and moved back to full extension (Fig. 308). Baldwin has obtained excellent results working on similar lines.

The Hip-joint

We will not deal here with fixation of the hip-joint due to adhesions of a slight character, which can be dealt with in the massage department or gymnasium, but will direct our attention to the graver types, which, for convenience of description, may be divided into groups:

(*a*) Fibrous fixation due to prolonged immobilization—usually found in connection with fracture of the femur—which has become septic.

(*b*) Gunshot injury to the femoral neck or trochanter with considerable scarring.

(*c*) Painful hips with limited movement, such as hypertrophic osteo-arthritis.

(*d*) Bony ankylosis.

The deformities in connection with the hip-joint are familiar to us all from association with tuberculous disease. With few exceptions similar deformities are present in war injuries. They are flexion, adduction, and usually some internal rotation. Tilting of the pelvis gives rise to considerable apparent shortening. In the earlier stages, before they appear at our orthopedic centers, many exhibit abduction and external rotation, but this is usually a transient stage. With the advent of flexion and adduction, lordosis is associated.

All flexions of the hip-joint the result of sepsis should be dealt with in as gentle a manner as possible. The lighting up of sepsis is a grave and often fatal calamity. Forcible movements and operative procedures should be delayed until risks are reduced to a minimum.

(*a*) Deformities due to fibrous fixation, the result of immobilization, can be treated without fear of any reaction in the joint. However, as we generally have a complication in the existence of an old fracture of the shaft, the greatest care should be taken not to do damage to this. If stiffness is not extreme, the old fracture should be protected by splints, and the sound thigh bent on to the abdomen to obliterate the lordosis, while the flexed thigh is gradually straightened. If it is found

that this cannot be done without great force, the manipulation should cease, for it is very easy to fracture the neck of the femur.

The thigh, still being protected by splints, should be placed upon an abduction frame which will obliterate the flexion, shortening, and adduction. The correction will be simplified if the adductors are contracted by subcutaneously dividing them. When the deformities are corrected it will be found that the pelvic spines are on the same plane, and that the thigh of the good leg can be placed on the abdomen without causing flexion of the unsound limb. A Thomas knee splint will replace the abduction splint, and movements of the hip may be resumed. If after correcting the deformity the hip remains stiff and painful, it should be fixed in the best possible position until reactive change has passed.

If the stiffness does not wear away, but reacts to any attempt at movement, it should be dealt with as a case of arthritis, and, as soon as the fracture admits of it, the hips should be fixed for walking. At a later date movements may spontaneously appear, and then the surgeon's aid will be productive.

(*b*) Where the deformity follows a gunshot injury through the neck of the femur, treatment is attended with grave responsibility. If the fracture was septic, the bone will remain very soft for months, and it is much better to allow the deformity to remain indefinitely—twelve months or two years—before placing on an abduction frame for gradual straightening.

Where fracture of the trochanter alone exists, this precaution is not needed, and the limb can at once be placed on an abduction frame.

(*c*) Painful hips with limitation of movement have frequently been noticed among the men, but more particularly among the elderly. These have been the result of exposure and often of hard marching, and have resulted in what we may turm a "traumatic osteo-arthritis." They are not the result of injury from missiles. In the young this condition becomes stationary. In the old it is nearly always progressive. The *x*-rays show osteophytic changes, as in osteo-arthritis. In both classes the condition is often associated with adhesions which still further limit movements and give rise to pain.

Considerable improvement follows a careful stretching of adhesions in the case of the young, followed by gently conducted exercises by a trained gymnast.

In the elderly it is advisable to rest the joint and to keep it under restraint during walking. On several occasions we have had to operate upon these joints when they have been exquisitely tender—neither allowing the patient to sit nor to lie in comfort. When this has been complicated by stiffness of the opposite hip the condition is deplorable, and requires a drastic surgical attack. Excision of the head of the bone is obviously a very serious operation in men over fifty. Great shock is associated with disarticulation of the head. We have, therefore, had recourse to an operation which we have found helpful on many occasions before the war. It allows of mobility, it does not involve

removal of the head, it is rapidly performed, and there is scarcely any shock. It consists of pseudarthrosis of the hip, leaving the joint *in situ*, and will be described later.

(*d*) Bony ankylosis of the hip is not very common. Its treatment can be discussed in association with conditions which can clinically be scarcely distinguished from it. A hip which is fixed at a good angle, whether by bony or short fibrous but sound ankylosis, should be left alone unless some exceptional reasons exist. Such a hip will bear weight without complaint and will give very little inconvenience. We know many instances where men can walk ten miles with ease in spite of this condition. In the lower extremity more than in the upper stability counts, and operations should be discouraged.

If the ankylosis is in a bad position this should be corrected by one of the following operations:

(*a*) Transtrochanteric osteotomy. (*b*) Subtrochanteric osteotomy. (*c*) Removal of a wedge.

(*a*) **Transtrochanteric osteotomy** gives the most accurate mechanical result. It should be practised in all cases of bony fixation where the femoral neck is not absorbed, and where there is no marked pathologic displacement. It may be done subcutaneously with a saw or by an open osteotomy.

(*b*) **Subtrochanteric osteotomy** is indicated where we wish the incision to be away from the old seat of mischief, or where the fibrous ankylosis is in process of becoming sound. It is contraindicated where the flexion is extreme, as the upper end will form a sharp prominence in front.

(*c*) A **wedge operation** is indicated where the neck and head of the femur are absorbed and the trochanter raised; in pathologic dislocations and in conditions where a mass of bone has to be penetrated. Here also the adductors must be severed.

Before fixing the patient in an abduction frame we often apply a pulley to the limb and bring the pelvis down on its adducted side. The degree of abduction at which to fix the limbs depends upon the shortening. The greater the shortening, the greater the abduction. It is now noted that the length of the limbs may be equalized in one of two or in both ways—either by lessening the practical length of the sound limb or increasing that of the short one. By osteotomy and extension a slight lengthening occurs, and by the osseous union of the femur in abduction with the pelvis the elevation of the pelvis on the opposite side is effected. With an abducted thigh in one piece with the trunk it is clear that the limb can only be adducted at the cost of elevating the pelvis on the sound side, and in this way several inches of shortening may be remedied. Theoretically, one should be content to bring the anterior spines of the pelvis level, but no harm comes if the adducted side is slightly abducted to remedy the effect of the real shortening.

The Mobilization of Ankylosed Hips.—Apart from the exceptional case where a patient insists on having movement, which he

regards as more important than stability, I would confine mobilizing operations to

(*a*) Cases of double ankylosis. (*b*) Cases of unsound ankylosis with adduction.

Even in a case of unsound ankylosis we should explain to the patient that a sound ankylosis could be assured him by operation, which would include a correction of his deformity and relieve him of all pain.

In double ankylosis operation is obviously imperative, and if the ankylosis is bony with the usual deformities, one limb should be submitted to osteotomy and the other to pseudarthrosis. The shorter limb should remain ankylosed, as pseudarthrosis or excision is followed by some shortening.

The operations from which a choice can be made are:

1. Excision of the head. 2. Pseudarthrosis to reconstruct the joint. 3. Pseudarthrosis without removing the femoral head.

The choice between an arthroplasty and an excision is often difficult.

An excision should be reserved for cases

(*a*) Where disease is present. (*b*) Where there has been much comminution. (*c*) Where the contour of the bones forming the joint is lost. (*d*) Where pathologic displacement has occurred.

The Operation of Excision.—The posterior approach is to be preferred to the anterior, and either the longitudinal or the Kocher incision can be used.

Arthroplasty.—Murphy's operation, as described by Binnie, but with a goblet incision, the stem of the goblet passing vertically over the trochanter, is sound and practical.

In a personal communication Sir Harold Stiles has described an arthroplasty of the hip whereby he dispenses with fascial intervening flaps and trusts to Horsley's wax.

Pseudarthrosis of the Hip Without Disarticulation of the Head.—This operation is reserved for elderly and fragile folk who have extremely sensitive hips, and who cannot stand the shock of disarticulation. It is also suitable for cases where a mass of bone has formed around the joint. It results in an excellent mobile hip, but a caliper has to be worn for some months. It is an operation devised to avoid friction, which is the cause of the acute pain in these cases. The operation consists in removing a slice of the great trochanter, chiseling through the neck, and screwing the separated portion of the trochanter to the proximal end of the neck in order to avoid union of the fragments.

The operation, which is not admissible in the case of children, is performed as follows: A longitudinal incision is made about 6 inches in length with the upper border of the trochanter in its center. An incision is made across the base of the trochanter just below the insertion of the gluteal muscles. A slice of the trochanter from this point to its junction with the neck above is sawn or separated by a very wide osteotome and retracted upward. The capsule is now opened and the head separated from the neck with an osteotome. Extension is next put on the femur, and the trochanter with its muscles attached is screwed

on to the head of the femur, which remains in the acetabulum. Deep and superficial sutures complete the operation. In the case of a tender joint, to avoid impinging, it may be necessary to remove a portion of the neck. In the case of an ankylosed sound joint the neck should be divided close to the acetabulum.

After all of these operations the limb should be kept at rest for about nine days, and then very gentle passive movements should be practised. A caliper splint should be worn in order to permit of walking without allowing any strain on the joint.

Stiff and Ankylosed Knee

We have already drawn attention to the fact that fractures about and into the knee-joint sometimes present a most obstinate rigidity.

Fig. 309.—Contracture of Left Knee-joint. (Naughton Dunn's case.)

The rigidity is so marked that very forcible efforts at flexion under anesthesia utterly fail even to gain a few degrees. Furthermore, such cases will sometimes yield to the influence of gravity and gradual pressure, and on page 681 we have described how best to attain this. In certain cases under anesthesia a limited flexion can be recovered, but any attempt at increasing this is so resisted by firm tissue that the surgeon has to desist. If such a limb is fixed by splint or plaster in the newly gained position and kept fixed for a week or so, a further gain

can often be secured under another anesthesia. This can be repeated until a fair range of movement is acquired. The fixation of resisting

FIG. 310.—SAME CASE AS FIG. 309 WITH TURNER'S SPLINT APPLIED.

tissue under strain renders such tissue less obstructive. A recognition of this fact will prove very helpful to us in dealing with obstinate stiffness (Figs. 309–311).

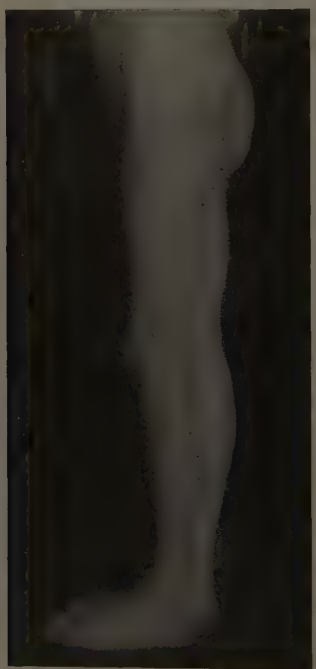


FIG. 311.—SAME CASE AS FIG. 309 AFTER TREATMENT. (Naughton Dunn's case.)

If when flexion is obtained in this way the limb remains firmly flexed and resists attempts at extension, we are not making progress. If after extension has been attained it again becomes rigid in extension after reasonable rest, we may be sure that we are being met by tissues which undergo reaction of a type which does not admit of further force.

When strong periarticular adhesions are thus stretched a certain transient degree of stiffness in the new portion will occur, but after a short course of massage and voluntary effort this will disappear. The advantage of gradual stretching over rapid tearing is that hemorrhage and excessive inflammatory reaction are avoided. There is a still further and very vital reason why excessive force should not be applied, for instances have happened where the patellar tendon has been torn, the patella fractured, and we have also met with cases where the quadriceps has been ruptured.

In injuries to the knee occurring in the war forcible manipulation has but a very limited field of application, and should be confined to the lighter type of so-called periarticular adhesions; and in the more rigid type of case the aim should be if anesthesia is employed to obtain only a few degrees of movement in successive stages.

Stiffness of the knee requiring surgical intervention are:

1. Periarticular adhesions. 2. Muscular adhesions to the bone. 3. Scarring and shortening of capsule. 4. Intra-articular adhesions due to arthritis or fracture. 5. Fixed patella. 6. Bony ankylosis of femur and tibia.

We have already referred to the treatment of periarticular adhesions.

Muscular adhesions interfering with flexion are generally associated with the quadriceps. If the muscle is firmly bound down the rigidity if the knee is very marked. These are the cases where surgeons point out that after forcing the knee they have gained a slight degree of movement. If the knee is examined, however, it will be found that they have either lengthened the patellar ligament or sometimes ruptured it. These cases should never be subjected to forcible movement. They have often been associated with a compound fracture, or suppuration in muscle-sheaths, or osteomyelitis.

The operative treatment for this condition is to detach the muscle from its adhesions, and to place a living flap of fat and fascia between it and the bone. The knee should be kept flexed during healing, and the muscle subjected to faradic stimulation.

Certain cases have suffered losses in muscle structure which has resulted in shortening. Operative elongation of the quadriceps tendon should be considered.

Shortening of Capsule.—The *x*-ray picture may exhibit a perfectly normal joint. The patella is free. There is no undue tension of the ligamentum patellæ, the quadriceps is not adherent, and yet the knee is firmly rigid. With these symptoms we can safely make a diagnosis of tense or contracted capsule. This should be treated first of all on the lines laid down in regard to severe periarticular adhesions, and if the rigidity still persists operative interference may be called for.

Operation.—A curved incision should be made from the femoral attachments of the internal lateral ligaments to the tubercle of the patella. The capsule is exposed. This can be incised by a curved incision extending from the anterior aspect of the ligament. The patellar tendon need not be divided if it does not obstruct; if it does, it can be elongated by a **Z** incision. The operation is simple, and should involve no risk. We have seen two excellent results from this operation.

Intra-articular adhesions are treated by gradual flexion under careful observation. If signs of severe inflammatory reaction should appear, treatment by this method should cease. A little pain and some effusion need not interfere with the stretching. Severe pain with rise of temperature should warn us of trouble.

Fixed Patella.—The patella is sometimes bound down by adhesions to the femur, and this alone will cause fixation. If the adhesions

are light they may be sometimes broken down by manipulation and exercise. If not, the bones may be fixed by operation. If the attachment is bony, the bones may be separated by chisel and a flap of fascia be introduced. If the bony attachment is extensive and rugged, the bones should be made smooth and level. Horsley's wax can be rubbed into the femoral erosion and fascia laid upon the surface of the patella.

Bony Ankylosis of the Knee-joint.—If ankylosis is complete and the bones are in good position, no surgical interference is needed.

Arthroplasty of the knee has no place in military surgery.

Cases have been seen where a gunshot wound, not complicated by sepsis, has caused a very limited ankylosis. Such conditions can be operated upon with advantage if the joint is otherwise healthy. It is better not to introduce flaps of tissue, but, after chiseling through the obstruction, to excavate the attachments, making them saucer shape, rubbing in Horsley's wax, if possible, keeping the knee flexed or in any position whereby the raw surfaces are kept apart.

Ankylosis in Bad Position.—(*a*) Flexion. (*b*) Lateral deviation. (*c*) Recurvatum.

Flexion of the Knee.—If the knee is flexed and sound and painless, with no more than 30 degrees of flexion, it is best to leave it alone. If the flexion exceeds that, an operation is advisable.

Operation.—A wedge of bone should be removed from the front of the knee, so that when the bones are wedged together firmly the knee should remain at an angle of about 15 degrees. We have always advised placing the knee-joint fully extended while we wait for an ankylosis to occur in inflammatory conditions, and also where we have to perform a classic excision. To keep such knees in a slight degree of flexion is often difficult and jeopardizes union. When, however, we resect a wedge, these difficulties do not arise, and an angle of 15 degrees gives a very useful limb from the point of view of function. Supracondylar osteotomy, unless planned to avoid recrudescence of sepsis, is inadvisable, as the result is never so artistic, more especially if the flexion is marked.

Lateral deviation should be treated as in a case of genu valgum by a supracondylar osteotomy.

Genu Recurvatum.—This is best treated by supracondylar osteotomy, care being taken to place the upper fragment well forward. It is not necessary to remove a wedge. After excision and esteotomy a caliper splint should be worn for three months.

The Ankle-joint

Stiffness of ankle may be due to:

1. Periarthritic adhesions. 2. Fracture dislocation of the astragalus. 3. Malunited Pott's fracture. 4. Chronic septic arthritis. 5. Bony ankylosis.

Periarticular adhesions are treated on similar lines to those of other joints. Many of the disabilities of the anterior portion of the foot are due to stiffness of the ankle, and these often consist of nothing worse than adhesions, and are easily rectified by manipulation and massage.

Old Fractures and Fracture-dislocation.—If the fracture was not a compound one and the displacement is not marked the disability will not call for a cutting operation. An anesthetic and thorough manipulation, followed by massage and exercise, are alone required. The full range of movement after this injury is often unavailable—more especially if the astragalus has been crushed into the os calcis. If either the anterior half or the posterior half has been displaced it should be removed by operation. If both are displaced—one half forward and the other toward the tendo achillis—the complete astragalus should be removed. If the astralagus is removed care should be taken that the foot is not displaced forward. The os calcis should not be allowed to slip out of the tibiofibular socket, or a varus deformity will occur. After the operation the foot should be kept at complete rest for a fortnight before starting movements.

Malunited Pott's fracture, either simple or compound, will sometimes result in a firm fixation of the ankle, and operation must be directed to correct this faulty alinement. The astragalus in such a case will often be separated from the internal malleolus. The correction of the deformity requires an operation.

The **simplest operation** consists in an osteotomy of the fibula at the point of fracture, snd the removal of a small wedge including the line of fracture in the tibia. By means of a Thomas wrench the eversion is corrected, the complete operation being effected in a very few minutes. After a few weeks the patient is allowed to walk about with an outside iron, and the heel of the boot raised on the inner side in order to maintain a correct deflection of body weight upon the ankle. If the fracture is a compound one and has resulted in a septic arthritis, removal of the astragalus or a cuneiform exsection is indicated.

In **chronic septic arthritis,** which has resulted in a painful condition of the joint with limited movement, arthrodesis is best unless there is much destruction of the astragalus.

Operation.—This is best done by a vertical incision over the front of the joint, and with a curved chisel stripping the joint of its cartilage, including a thickness of about $\frac{1}{4}$ inch of bone. There is no necessity to avulse the astragalus. Osteotomy of the malleoli will enable us to bring the bared edges into close apposition to the astragalus.

If there is much bone involvement a classic incision should be done, but this is best avoided if it be at all possible.

Bony ankylosis should only be interfered with in order to place the foot in a good position. The best position for an ankylosed ankle is, as we have already explained, at an angle slightly more dorsiflexed than a right angle. This allows of a more elegant gait than when it is at a right angle, as the patient uses the foot as a rocker anteroposteriorly, and is not obliged either to rotate his hip or hyperextend his knee.

Varoid and valgoid deformities are corrected by cuneiform osteotomy.

Flail-joints and Their Treatment

The loose or flail-joint is a very common product of war injuries. Such a joint has a very imperfect function, and, for practical purposes, is almost useless, because, although the muscles may be present, the bone ends lack apposition, and, therefore, there is no fulcrum on which they can act.

Flail-joints arise from destruction of the joint ends by gunshot injuries and from the extensive operations done for the treatment of these conditions.

In order to prevent the occurrence of a flail-joint three principles should be observed:

1. The resection of the injured joints should be as conservative as possible, those pieces of bone only being removed which are damaged and severed from their soft-part connections.

2. Avoid long-continued extension. It is not infrequent for comminuted fracture of the elbow-joint, which has been treated by resection, to be put up in a straight Thomas' arm splint, and for extension to be maintained in this position for several months. Such treatment will certainly produce a flail-joint.

3. In the early treatment of the injured joint ankylosis and not mobility should always be the aim of the surgeon. That is to say, after the conservative resection has been performed the limb should be so placed as to bring the bone ends into near contact, and it should be retained in this position for a prolonged period. The position chosen for retention should be that which will give the best possible use of the limb if stiffness results.

Treatment of Flail-joints.—This may be considered under three headings:

1. Removal of infected tissue. 2. Immobilization by splint or plaster. 3. Operation.

Removal of Infected Tissue.—In many cases undue mobility of the joint is kept up by the presence of dead bone and scar tissue. Existing sinuses should be freely opened and all dead bone removed, and as much scar tissue dissected out as is possible. At the conclusion of this operation the limb should be put up in the optimum position and thus be immobilized until the healing has taken place.

Immobilization by Splint or Plaster.—In the majority of cases a very great improvement of the loose joint will take place if the limb is forced into such a position as will shorten the fibrous tissue between the bone ends. The bones should be forced into as close an apposition as possible, avoiding the interposition of the soft parts, and the limb is then encased in plaster of Paris for three months. During this time all the scar tissue between the bones undergoes the natural process of contraction, and in this way will tend to form a fairly good imitation of the natural ligaments of the joint.

Treatment by Operation.—Two types of operation are possible for flail-joints. In the first an attempt is made to preserve the mobility and merely to correct the instability of the joint. In the second the

joint, as such, is abandoned, and the bones are fixed together so as to produce ankylosis.

It is hardly possible to indicate in general terms the rule which should guide the selection between these two operations. Usually, an attempt is made to retain the movements of the joint in the first place, but if this has still left a weak and wobbly limb, the second type of operation is resorted to.

In the joints of the upper limb mobility is often more desired than fixation, whereas, in those of the lower limb, stability is of the first importance.

FIG. 312.—FLAIL SHOULDER WITH DESTRUCTION OF DELTOID.

Flail Shoulder.—When once the shoulder has become flail, it is a matter of considerable difficulty to restore the muscles to a sufficient tone to produce a useful joint. From a theoretic standpoint the shoulder is a joint in which the flail action is of least harm. Indeed, it may be stated that freedom of mobility in the shoulder is never wholly the cause of loss of function; it is rather a loss of control of this mobility by the muscles of the joint.

In the first place an attempt should always be made by keeping the arm in an abducted position for several months to secure the recovery of the shoulder muscles. If a prolonged trial of this method still leaves an arm which cannot be raised from the side by the patient's own effort, it is much better to proceed at once to an arthrodesis.

FIG. 313.—RESTORATION OF RIGHT SHOULDER BY MEANS OF A BONE-GRAFT. (Platt's case.)

FIG. 314.—ARTHRODESIS OF SHOULDER.
A bridge of bone unites the glenoid with the neck of the humerus. (McMurray's case.)

FIG. 315.—SAME CASE AS FIG. 314 SHOWING RANGE OF ABDUCTION AND MOBILITY OF THE SCAPULA. (McMurray's case.)

The method of procuring such fixation of the shoulder-joint has already been described in the preceding section, and this need not be repeated.

In a few rare cases where the upper portion of the shaft, as well as the head of the humerus, has been lost, it may be possible to replace this bone by means of a long graft. An example of such an operation is shown in the illustration, but it is very rare to have a case such as this, where extensive loss of bone is associated with a sound and healthy deltoid muscle.

Before the arm is fixed care should be taken to ascertain whether the scapula is mobile.

FIG. 316.—GROUP OF FIVE PATIENTS SHOWING RANGE OF ABDUCTION AFTER ARTHRODESIS OF SHOULDER. (Naughton Dunn's cases.)

The success of the operation depends on firm bony union between the humerus and scapula, and also upon the mobility of the latter. If the scapula is fixed the result of the operation is a tragedy, for then the patient will have an abducted arm which he cannot lower.

Flail Elbow.—For this, as in other cases of loose joints, there are two methods of treatment—the non-operative and the operative—and it is wise to do the utmost possible by the former before embarking upon the latter.

Non-operative treatment consists in the measures which have been described, and it is often possible to remove a very large amount of scar tissue from between the bone ends, the forearm then being put up at an angle of 60 degrees of flexion, and retained there for several months. A word of caution, however, is necessary at this stage. If

the elbow is put up in a flexed position by plaster of Paris which extends up to the level of the axilla only, the forearm, together with

FIG. 316a.—CASE OF FLAIL JOINT. (Platt's case.)

the plaster of Paris, will tend to slip downward by the action of gravity, and thus quite defeat the object of the treatment. Therefore,

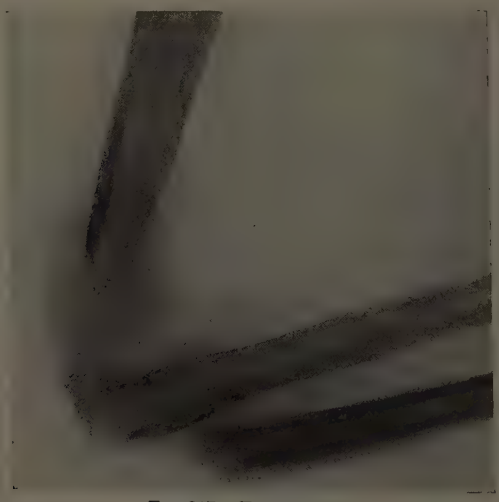


FIG. 317.—FLAIL JOINT.
The type of case in which it is very difficult to obtain stability suitable for arthrodesis. (McMurray's case.)

effective immobilization of a flail elbow-joint will necessitate the provision of some method of holding the weight of the forearm firmly up

to the shoulder. This may be done either by the use of an abduction splint or else by bringing bands up from the elbow splint over a shoulder-cap and under the opposite armpit.

Before deciding to resort to an operative fixation of a loose elbow-joint it is always worth while to fit the patient with a hinged elbow splint, providing this also with an attachment to the shoulder-cap, which will support the weight of the forearm. In the case of those patients whose occupation renders it very important to have a movable elbow, it is worth while persisting in this treatment for at least twelve months before abandoning the patient to a stiff arm. During the whole of this time every possible means should be taken to improve the strength and tone of the muscles, particularly the flexors, so that the patient may regain control over his limb.

Operative Treatment.—Operations on a flail elbow designed to retain the mobility of the joint need not be described here because they have already been dealt with in the section on Stiff Joints.

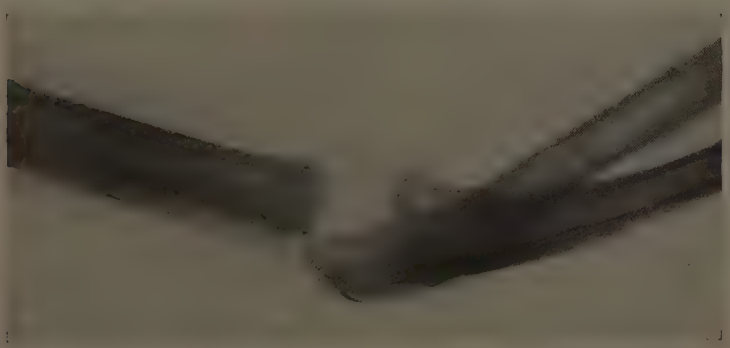


FIG. 318.—FLAIL ELBOW, THE TYPE OF CASE IN WHICH AN ARTHROPLASTY WILL GIVE A FAVORABLE RESULT. (McMurray's case.)

Operation of arthrodesis, or fixation of the elbow-joint, is a simple one in theory, but apt to give very disappointing results. The failure to fix the bones is due principally to the fact that the arm is liable to hang by the side, and gravity thus pulls the joint apart, and also to the poor vitality of the bone ends and to the restricted exposure of their tissues by the surgeon.

One of two methods may be adopted to produce bony fixation of the elbow:

In the first, the humerus is definitely wedged between the upper ends of radius and ulna, and there fixed by a transverse bolt and nut or kangaroo tendon, the adjacent surfaces of the bones being bared so as to give close contact.

In the other type of operation the ends of all three bones are split, comminuted, and divided in such a manner as to produce a large area of raw bone surface.

Flail Hip.—In the ordinary sense of the word, this condition is very rare as the result of gunshot injuries, but some degree of the con-

dition may result when the head and neck of the femur have been lost. Under these circumstances it is usually sufficient to correct the adduction by the division of the adductor muscles, the limb being put up for some time in full abduction. If a considerable amount of the bone is lost, so that no weight can be borne upon it, the patient should be fitted with a jointed caliper splint, by means of which he is often enabled to walk with comparative ease.

Flail Knee-joint.—The truly flail knee is always the result of the extensive resection in which not only the articular end of the bones but also the lateral and crucial ligaments have been removed. The only possible treatment for such a condition is a fixation of the knee-joint by bony ankylosis.

It is probably best to join the femur and tibia in a straight line, but a few degrees of flexion are considered by some to be an advantage. The more important point consists in the securing of rapid and firm bony union. Uuless special precautions are taken to this end, a fibrous ankylosis is very liable to occur, and this will necessitate the wearing of an apparatus permanently.

To secure a firm and rapid bony union between the tibia and the femur the ends of both bones should be freely cut, drilled, or chiseled, so as to provide a number of bone chips from which new bone can be laid down. The more precise method of achieving this result is to turn up a long bone-graft from the front of the tibia and to embed this in a groove cut down the front of both bones.

Ruptured Crucial Ligaments

There is no joint in the body where stability is of more importance than in the knee-joint.

It is in this that the minor degrees of unnatural mobility are observed which greatly interfere with walking, which would be of no importance in one of the joints of the upper limb. Thus the stretching or rupture of either of the lateral ligaments produces lateral mobility of the knee-joint, with great weakness of the leg, speedy fatigue in walking, and secondary malformations of the feet.

Rupture of the crucial ligaments in the interior of the knee-joint may also occur apart from any other obvious injury, and this accident, which has become so well recognized during the war, leads to a permanent definite disability, the discussion of which merits our attention. The anterior crucial ligament running from behind the femur forward to the tibia has the function of preventing the tibia from slipping forward. When it is ruptured the patient's knee becomes partly dislocated by the head of the tibia slipping forward with every step he takes, or sometimes only occasionally, with some twisting movement. The posterior crucial ligament which runs from the femur downward and backward to the tibia below has the function of preventing the latter bone from being displaced backward. When it is ruptured the head of the tibia slips back on the femur when the joint is fully extended and the weight is thrown upon it. This latter condition is frequently as-

sociated with an injury to the posterior ligaments of the knee-joint and some degree of genu recurvatum.

Various methods have been suggested for the treatment of this internal rupture of the ligaments of the knee, but hitherto they have not been sufficiently promising of success to warrant the majority of surgeons adopting them, and the treatment has been that of a hinged knee splint, which allows of movement in only one direction. During the war, however, one of us (H. G.) has evolved a method of treating the ruptured crucial ligaments which has yielded a gratifying measure of success.

FIG. 319.—DIAGRAM OF KNEE SHOWING ILIOTIBIAL BAND AND BONES BORED FOR NEW ANTERIOR CRUCIAL LIGAMENT.

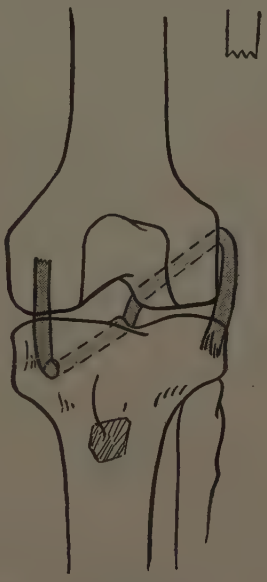


FIG. 320.—NEW CRUCIAL LIGAMENT FORMED FROM ILIOTIBIAL BAND.

The principle of this operation consists in utilizing a piece of the fascia lata or of one of the tendons of the knee-joint in order to replace missing crucial ligaments.

Thus, to replace the anterior crucial ligament a band of the fascia lata, 6 inches long, is isolated on the outer side of the thigh, its attachment to the head of the tibia being preserved. The cavity of the knee-joint having been exposed by an upward reflexion of the patella and its ligament, the band of fascia is passed successively through holes drilled in the external condyle of the femur, and the inner tuberosity of the tibia.

In its passage across the knee-joint the new ligament occupies exactly the same position as did the crucial which it has to replace (Figs. 319, 320).

Alwyn Smith has suggested an improvement on this operation which consists in allowing a sufficient length of fascial band to bring the free end upward from the inner tuberosity of the tibia to the internal condyle of the femur, thus supporting the internal lateral of the knee-joint which is frequently damaged at the same time as the anterior crucial.

The operation for the posterior crucial consists in isolating the tendons of the semitendinosus and gracilis on the inner side of the thigh,

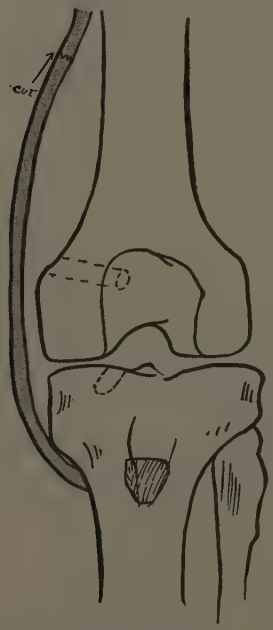


FIG. 321.—DIAGRAM OF BONES OF KNEE AND SEMITENDINOSUS TENDON.
The tibia is grooved and the femur bored for a new postcrucial ligament.

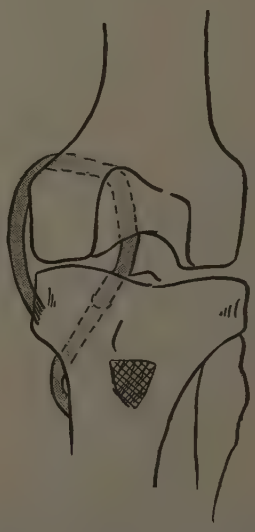


FIG. 322.—NEW POSTERIOR CRUCIAL LIGAMENT FORMED FROM THE SEMITENDINOSUS TENDON.

and then bringing them through the knee-joint to replace the posterior crucial. The joint being widely exposed, the tendons are first brought forward through the cavity of the joint by an instrument thrust through the posterior ligaments, merely grooving the head of the tibia. They are then drawn through the hole bored in the front portion of the internal condyle of the femur, and the free end brought down to the tibia to act as an accessory to the internal lateral ligament (Figs. 321, 322).

CHAPTER XXIV

MILITARY SURGERY OF THE VASCULAR SYSTEM*

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Part I

Military Surgery of the Heart

FOREIGN BODIES IN THE HEART AND PERICARDIUM

The extraction of foreign bodies from the heart, pericardium, and great vessels constitutes one of the crowning triumphs of surgery in the late war. Two causes have come into play in extending and systematizing this newly developed and boldest phase of cardiac surgery: First, the greater frequency with which artillery projectiles and explosive shells have been used in the war. Second, the more systematic and routine examination of thoracic organs by *x*-rays, not only radiographically, but radioscopically, which has revealed the presence of projectiles in the heart, pericardium, and great vessels where their presence was not even suspected. This is well shown by the general statement made by Ombredanne and Ledoux-Lebard, in their admirable little war manual on the localization and extraction of projectiles (1919), to the effect that they find from French sources a total of 2000 extractions of projectiles made with the assistance of radiographic and other localizing aparatus, with failure to extract the bodies in *only* 3 cases out of the whole number; that is, 0.15 of 1 per cent. These figures quite suffice to show not only the wonderful extent but also almost incredible success which has attended the development of this new and highly specialized branch of surgery. The relative tolerance of the heart for many of these foreign bodies, which was already well known by experimental and clinical observation, has been confirmed, and the tolerance of the heart for the manipulations and operations required to extract them has been more than confirmed. It is impossible at the present time to give a full estimate of the aggregate number of operations performed on the heart for the extraction of these foreign bodies by the surgeons of the different belligerent armies, but the accessible individual and collective reports during the war are amply sufficient to prove that, whether in the acute or urgent period immediately following the injury, or when the acute period has subsided and a stage of relative tolerance has been established, a deliberate, well-planned radiosurgical operation, especially in qualified hands, can be performed with a fair prospect of success.

* Supplementary to Chapter LXX, Vol. V, p. 17.

The Migrations of Projectiles in the Heart and Blood-vessels (Clinical Data)

The migrations of bullets and foreign bodies through the channels of the circulation may be classed into two great groups:

First: Missiles and foreign bodies which originally entering the *left chamber* of the heart are carried by the blood-stream into the aorta and thence to the peripheral arteries, where they are arrested when the lumen of the vessel is too small to permit their further progress; for example, the axillary and the femoral arteries. Of this class we have numerous examples, for instance, among the older cases Munzenthaler (1837) reported long ago that a number of fine shot which had penetrated the left auricle had found their way through the left ventricle and into the distal parts of the aorta. Schloffer (1903) reports the migration of a revolver bullet, which, entering the left auricle, was found blocking the right axillary artery, from which it was extracted by arteriotomy. In the most recent war observations Boeckel (1917) reported that a bullet, previously localized by the fluoroscopic screen in the left heart, was found obstructing the femoral artery, where it caused gangrene of the ischemic limb, requiring an amputation. de Rouault relates the case of a soldier who had been shot in the arch of the aorta; the missile dropped into the left femoral artery, causing ischemic paralysis and gangrene of the limb, followed by death. O'Neill tells of a fragment of a shell which, penetrating the left heart, was found blocking the common iliac artery. The fragment had been seen fluoroscopically in the left ventricle three days previously. Death occurred from gas gangrene in the corresponding limb. In Perdoux's case, reported by Baumgartner, a bullet from a machine gun penetrated the *left* ventricle on September 22, 1918. It was movable, but still in the heart, on October 12th. On October 22d another fluoroscopic examination demonstrated the absence of the projectile. On the same day it was discovered in the right common iliac artery. The projectile appeared to be lodged at the bifurcation. The same location was confirmed on December 18th. On December 21st a laparotomy was performed and the projectile extracted by the transperitoneal route and the incision in the artery closed by suture. Unfortunately, a thrombus filled the external iliac at its bifurcation, and the circulation through the main artery was not re-established. However, the collateral circulation had been well established and no serious harm came to the limb. The most remarkable feature of this case, apart from the migration, is that there was no pain, no acute symptoms, or indication of ischemia to tell when the blockade of the artery had occurred. The patient made a good recovery without leaving any symptomatic relics of the cardiac lesion.

In a *second group of cases* the foreign bodies travel with the *venous current*, and the projectile is displaced from the periphery to the heart, where it remains, or is ejected into the pulmonary circuit through the pulmonary artery and its branches; or, if in the right chamber of the heart, it may reverse its course and travel from the heart to the per-

iphery through the cavæ and against the venous current. Among the earliest observers, Simmonds, quoted by Gross, tells of a pistol bullet which penetrated the right ventricle and was found subsequently lodged at the origin of one of the common iliac veins. One of the most remarkable and recent war cases is that reported by Grandgérard: A soldier was wounded October 10, 1916. One week later, a light local pain being the only symptom, an *x*-ray examination revealed a mass in the *right* auricle, which was subject to rapid and regular movements having the character of an elliptic vortex. A little more than an hour later he was again placed under the screen, when no sign of the missile could be seen. A shadow was visible, however, at the level of Scarpa's triangle. On further examination a few minutes later the shadow had again disappeared, but was readily found in the pelvis on a level with the right sacro-iliac joint. Two days later, through a median abdominal incision, an attempt was made to locate and remove the bullet, but the operator was unable to reach it in safety. The bullet was located in the internal iliac vein, where it was fixed by ligating the vein on the cardiac side and allowed to remain *in situ*. Gregory observed a soldier wounded in the chest with a shrapnel bullet on January 9th. The bullet was located fluoroscopically in the chest and, at first, thought to be in a bronchus, where at times it oscillated quite violently through a distance of about 1 inch. Two days later the fluoroscope showed that the bullet was missing from the chest and had migrated to the abdomen, and was 1 inch to the right and 1 inch below the umbilicus. On January 26th symptoms suggestive of peritonitis developed and operation was undertaken. The bullet was found behind the peritoneum, on the inner side of the ureter, in the internal iliac vein. It was removed and bleeding controlled—but the patient died from peritonitis a few days later. Gregory contends that the bullet originally was lying in the right auricle and was subsequently dislodged into the inferior vena cava, and thence to the internal iliac vein, where it was extracted.

But while these cases of migration against the current are multiplying, it is a much more frequent occurrence to see them following the drift of the venous current.

Among the early observations of wandering missiles, as observed in the World War, is that reported by H. M. Lyle, of New York: A Zouave had been hit in the thigh by a shell fragment. The thigh and abdomen were negative to the *x*-rays. The wound was laid open and excised; the femoral vessels were found embedded in a clot, but apparently intact (operation four hours after injury). Death occurred four days later from a generalized gas bacillus infection. At the autopsy a rough shell fragment 1.5 by 0.9 by 0.5 cm. in size, weighing 1.81 gm., was found free in the cavity of the right ventricle. There were fibers of clothing adherent to the irregular surface of the shell.

As Bland Sutton remarks, the hepatic vein seems to be a convenient channel for metallic emboli. He refers to a specimen preserved in the collection of the British War office showing a hole in the hepatic vein

through which the missile reached the vena cava, the right auricle, and the right ventricle, where it lodged.

Ponzio also writes of a projectile which, entering through the iliac region, penetrated into the iliac vein and then into the right ventricle. For a while it caused much disturbance, but subsequently became dormant, and was so well tolerated that no operation was done.

Visconti records that at the necropsy of a man who had been shot in the upper spine he found the bullet lodged in the right ventricle. It had penetrated by way of the left branch of the *pulmonary* artery, on a level with the hilum of the lung.

Jaffe tells of a soldier in whom a bullet entered the vena cava by way of the pelvis, and was carried through to the right ventricle, where it was found lying beneath a flap of the tricuspid valve. In life the patient had only complained of pain in the heart.

From civil practice Colville records a case of a bullet traveling against the blood current, which entered the front of the chest below the clavicle and to the right of the right border of the sternum. There was no wound of exit. After a series of *x*-ray examinations of the abdomen and lower extremities the bullet was finally detected deep in the tissues of the left thigh, in the line of the profunda vessels, below Poupart's ligament. At the operation the bullet was found firmly jammed in the lumen of the vein. It was removed without difficulty, the vein being divided between ligatures. The patient made an uneventful recovery.

A number of other rare and curious cases of wandering projectiles and foreign bodies will be found in papers mentioned in the Bibliography.

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EXPERIMENTAL DATA ON THE MIGRATION OF FOREIGN BODIES IN THE CIRCULATION

The following papers should be read, as they give important experimental evidence of the varied migrations of shot, rice, and other foreign bodies introduced into the arteries and veins, and of the results of their migrations into the heart and lungs; the effect of the weight and size of the foreign body of gravity, and of posture: Monti and Ascoli: Il Morgagni, Oct. 12, 1916. Achard and Binet: Bull. Acad. Méd., Paris, July 16, 1918.

ROUTES OF ACCESS TO THE HEART. LESSONS GATHERED FROM THE EXPERIENCE OF THE LATE WAR

In Volume V of Keen's Surgery, under the headings, "Pericardiotomy" and the "Operative Treatment of Cardiac Wounds," the anatomic routes and surgical procedures which had been suggested up to 1909 to obtain access to this organ and in the extraction of missiles and other foreign bodies that might be lodged in its walls or cavities, were discussed with considerable detail. There was little to add to the discussion of the subject or to the general conclusions then expressed up to August, 1914. But the experience of the late war and the extraordinary increase in the number of casualties caused by the explosion of artillery projectiles and other foreign bodies has virtually created a new chapter in the history of cardiac surgery. Apart from the greater frequency of the lesions of the heart by projectiles, foreign bodies, etc., the frequent survival of the wounded from the immediate effects of the primary trauma with retained missiles in the heart, has revealed a greater relative tolerance for these bodies than was previously suspected.

The presence of these projectiles as revealed by radiologic methods has created a group of posttraumatic cases which come to the surgeon in a "cold" or latent stage, and in which the symptomatology and surgical indications for interference are very different from those offered by the urgent phenomena of the initial injury. In these cases the problem of diagnosis does not confront the surgeon with perplexing doubts. The presence of the missile in the heart or its immediate vicinity is proof positive of the lesion. Furthermore, the anatomic localization of the projectile and the foreign body has been fully determined by the radiologist—sometimes with almost uncanny precision and detail. The condition of the patient is not that of a shocked, exsanguinated, and often asphyxiated individual battling for life, giving the surgeon only a few precious moments to do his work to save life. These patients, on the contrary, come to the surgeon weeks, months, and years after the original injury has been inflicted, depending more or less upon the cardiovascular and respiratory disturbances and the gravity and persistence of the symptoms which are manifested after recovery from the primary trauma has been assured. Time is, therefore, afforded for the most thorough and satisfactory radiologic and clinical inquiry, and for the most deliberate and calm judgment

on the surgical indications in the event that the extraction of the projectile is deemed necessary or justifiable.

The lessons which have a direct bearing upon the surgery of the heart in general, and with reference to the extraction of foreign bodies in particular, may be briefly summarized into:

1. The indispensable association and collaboration of the radiologist with the surgeon for diagnostic and surgical purposes.

2. The proved efficiency of this combination has added vastly to the safety of intrathoracic manipulations and to procedures for the extraction of foreign bodies which hitherto had been regarded as largely impracticable.

3. Modifications in the technic of thoracotomy which, utilizing the older suggestions and methods, have been revised and extended in the light of a new and larger experience.

4. The disregard of the pleura and of the risks of acute surgical pneumothorax, contrary to all preconceived notions of the gravity of this complication in antebellum days.

In regard to **radiologic methods** it may be said in general terms that the one fact upon which all agree is that radioscopy with the fluoroscopic screen is far more important than radiography with plates. There is a great difference in the methods of radiology utilized for the localization of foreign bodies among the leading operators, as may be seen by comparing the technic of Pierre Duval, René LeFort, Ombredanne and LeDoux-Lebard, and Petit de la Villéon, who may justly claim a preponderance of experience and success in the extraction of foreign bodies. The relative merits of these methods are presented elsewhere in this volume and need not detain us here. It is only fair to state that there is a practical unanimity in recognizing the great value of other than *x*-ray localizers (electric vibrators, electromagnets). The induction balance of Hughes and its derivatives (audioscopic vibratory finger-tip of LaBaume, etc.), telephonic probes, and other known appliances which have increased in number and have been greatly improved in this war. These are also described in other chapters of this work.

Pneumothorax.—In 1909 we were deeply concerned with the effect of the sudden admission of air into the pleura and with the risks and dangers of an acute surgical pneumothorax. Therefore the division of thoracic operations into *intra-* and *extra*pleural was of great significance. The fear of traumatic or acute surgical pneumothorax dominated the minds of most surgeons, and the many devices and apparatus invented for operating under *hypo-* and *hyper*pressure attest the conviction which everywhere prevailed to the effect that the sudden collapse of the lung after the entrance of air into the pleura was a perilous complication and seriously interfered with the progress of thoracic surgery. The introduction of the Meltzer-Auer principle of ventilation of the lungs regardless of the intrapulmonary tension, by means of intratracheal insufflation, was a great advance, and relieved many operating rooms of the cumbersome appliances which were used to obtain *plus* or *minus*

tension in the lung. But even this last method, which is still a precious resource in neutralizing the effects of bilateral pneumothorax and whenever the mechanism of respiration is suspended, was found unnecessary by the pioneer French military surgeons of the recent war, who unhesitatingly and freely opened the chest whenever they deemed this necessary for their purposes. Pierre Duval's commentaries on this subject are worth quoting:

"Before the war the essentially French method of producing a total pneumothorax by a large pleural opening has been proved to be successful. Chest work during the war has shown that this procedure, which was formerly regarded as something exceptionally dangerous and bold, is entirely practicable, and constitutes the method of election in intrathoracic surgery. Apart from the fact that a gradually progressive pneumothorax is not dangerous, its presence is a great advantage in manipulating the lung. The delivery, inspection, incision, and suture of the organ are only possible when the lung is collapsed, etc."

LeFort, whose numerous thoracic operations entitle his opinion to serious attention, says: "Pneumothorax is remarkably well tolerated; there would appear to be no greater risks in opening the pleura than the peritoneum." Bazy, Delagenière, and Marion taught, long ago, that it should not be feared. "In fact, the production of open surgical pneumothorax appears to improve the condition of some patients." And he recites how an emphysematous alcoholic, from whom he had to extract a projectile from the mediastinum, calmed down and breathed naturally after the pleura had been opened, whereas his breathing was embarrassed before this was done.

LeFort was timid and very cautious in allowing air to enter the pleura in his early thoracic operations, but soon learned that his fears were groundless. Paradoxic as it may seem, the freer the incision, the better the pneumothorax is tolerated. Small incisions which allow the air to enter intermittently or irregularly cause a great deal more respiratory disturbance than the initial large opening of the pleura. He believed that small incisions allow the air to be retained in excess of that expelled through the wound in expiration, and that in this way a hypertension is produced in the pleura which causes them ediastinal septum to be displaced or deflected to the other side, thus encroaching upon the respiratory capacity of the other lung. LeFort believes that the flat collapse of the lung against the vertebral column in a state of complete atelectasis is a myth. A total collapse only takes place in the cadaver. In proof of this we see that even when the pleura is wide open a paroxysm of cough or violent inspiration will herniate the lung out of the chest. There is a dyspnea which appears invariably just at the moment the pleura is opened. This is not caused by interference with the oxygenation of the blood, but it is merely the consequence of a temporary disturbance in the respiratory equilibrium. One lung amply suffices to meet the respiratory requirements of the patient, especially when he is young, in anesthetic sleep, fasting, and in a state of complete muscular relaxation. This initial dyspnea soon disappears and the patient usually adapts himself promptly to the new conditions created by the pleural opening.

"Briefly, it may be stated that a large free transpleural incision is to be preferred to the small incision or to extrapleural methods, especially in dealing with projectiles lodged about the great vessels at the root of the heart or in the mediastinum. The extrapleural routes are chiefly indicated for septic cases in which a projectile is embedded in a manifestly infected space, a suppurating fistula or abscess, for example" (LeFort).

How to deal with the pneumothorax after the operation is completed is another controverted question which has been elucidated by the experience of the war. In all aseptic cases the thorax is to be closed hermetically, and the pleura, after a thorough toilet (removal of clot, wiping the pleural sac, lung, etc.), closed without drainage. The air in the pleura is allowed to remain and is absorbed in a few days after the intervention. These are LeFort's views. Pierre Duval prefers to aspirate the chest through the wound before this is completely closed. This, we believe, to be the safest practice.

The advantages of an early intervention in cardiac, pericardial, as well as pulmonary or mediastinal wounds is that the operation is performed in the period of contamination before actual infection has taken place, and the principles that have proved so successful in the treatment of injuries of the joints, with complete closure without drainage, after a thorough toilet of the joint—are applicable with even greater force in the pleura than in the joints. When infection exists, drainage in some form is unavoidable. What we have learned of the tolerance of the pleura and lung for pneumothorax applies as well to those injuries of the heart in which the pleura has been perforated (61 per cent.) and traumatic pneumothorax exists as a complication. In such cases there is no reason why the heart and pericardium should not be exposed by the freest intrapleural method of thoracotomy. On the other hand, when the pleura is not involved and there is no pneumothorax and the heart must be reached and freely exposed to extract a projectile embedded or held within its cavities, it is proper to consider the addition of a pneumothorax as a very undesirable complication which should be avoided if possible.

Thoracotomy.—The reports of the many operations which have been performed for the removal of foreign bodies in the heart or at the root of the great vessels show a great discrepancy of principles and procedures among even the most experienced operators. There is a great leap, for instance, between the practice of LeFort, who insists upon the importance of large space and plenty of room for the intrathoracic operations, and opens a large fenestra obtained by a trap-door osteoplastic flap involving the cartilages of the third to fifth ribs, and the small buttonhole incision, barely large enough to admit a long narrow forceps, that Petit de La Villéon has used so successfully in the extraction of pulmonary or mediastinal projectiles. While the intrapleural methods are necessary and unavoidable in dealing with *pulmonary* or mediastinal projectiles in the delayed or late cases, it is still very questionable in this particular class (retained heart projectiles in the latent or cold stage) whether the pleura must necessarily be opened to expose the heart in all its parts in order to accomplish whatever manipulations may be required.

Methods of Thoracotomy.—Duval, whose advocacy, in pulmonary surgery, of fearless opening of the pleura, regardless of the pneumothorax, has already been noted, has recently introduced a median *thoraco-abdominal pericardiotomy* which has the advantages of giving a maximum anatomic exposure of the heart and the great vessels without opening the pleura. This is a move in the right direction, and shows that no matter how tolerant the patient may be to an acute pneumothorax in *aseptic* conditions, it must nevertheless be regarded as a very undesirable complication at all times, but especially in the late or delayed extraction of cardiac projectiles.

Mediosternal (Extrapleural) vs. Lateral (Transpleural) Osteoplastic Thoracotomy.—We shall now illustrate the methods of thoracotomy adopted as typical procedures by the three surgeons who have had the

largest experience or, at least, contributed the largest personal documents to the recent war literature of the heart, chiefly in connection with the extraction of foreign bodies.

LeFort in his recent book (1918) bases his experience on 37 personal observations of foreign bodies in the mediastinal space, including 11 operations on the heart and pericardium, and 30 operations for bodies in the juxtamediastinal regions (ligament of the lung, hilum, pulmonary pedicle, etc.), also a series of other intrathoracic operations for stabs of the heart, massage of the heart, mediastinal abscesses, etc. In a general way the bulk of his intrathoracotomies has been of an atypical character, but nearly all intrapleural. He has adapted his methods to the depth and relations of the projectiles to the contained organs and

FIG. 323.—DÉLORME-MIGNON TRAP-DOOR OSTEOPLASTIC FLAP, INVOLVING SECTION OF THIRD, FOURTH, FIFTH, AND SIXTH RIBS AT, OR CLOSE TO, THE CHONDROSTERNAL JUNCTION.

Has been utilized successfully by R. Le Fort and other French surgeons in the extraction of projectiles and other foreign bodies in the chest and mediastinum. (From R. LeFort, Revue de Chirurgie, Tome 53, 1917.)

to other findings ascertained by radiologic examinations. Of these cases, 11 were for projectiles in the heart or its cavities, or in the pericardium, and to reach these has given preference to two typical methods.

1. *LeFort's Lateral and Anterolateral (Parasternal) Thoracotomy (Left Sided).*—Osteoplastic trap-door with the hinge on the outer (left) side: This is essentially the well-known procedure of Délorme. It usually includes segments of more than two ribs and sections of the third, fourth, and fifth cartilages for the larger explorations. This is his preferred method whenever the largest exposure is necessary (Fig. 323).

2. An intercostal incision without resection of the ribs, supplemented by the division of one or more costal cartilages on a level with

the sternum (Figs. 324, 325). The third intercostal space, with section of the third and fourth costal cartilages, or the fourth space with the fourth and fifth cartilages, are preferred for work on the heart.

This is the operation that Spangaro first systematically described as a typical approach to the heart, based upon Mikulicz's and Sauerbruch's early thoracotomies. Wilms and Iselin first clinically and independently confirmed the value of this method (1906). It is fully described and illustrated under the title of Spangaro's intercostal incision on pp. 63, 64 of Vol. V of Keen's Surgery. LeFort, in his re-

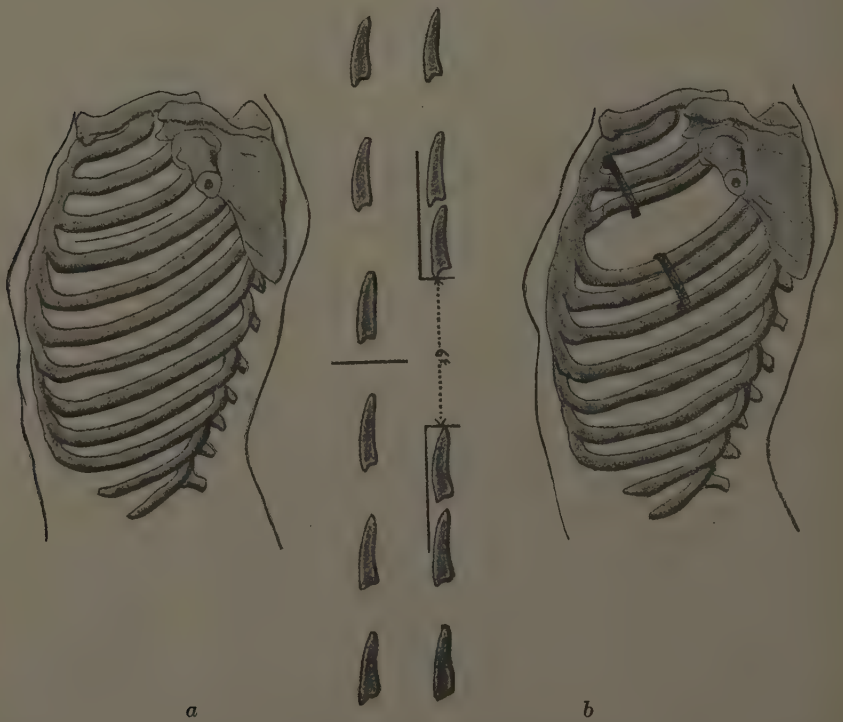

FIG. 324.—THESE DIAGRAMS SHOW THE EFFECT OF FORCIBLE RETRACTION OF THE RIBS IN ENLARGING A SIMPLE INTERCOSTAL INCISION *without* RIB RESECTION.

In the adult, the maximum limit of width is 6 cm. No further gain is possible on account of the obstacle offered by the adjoining ribs: *a* shows the line of incision, *b* shows the effect of retraction in increasing the aperture. In the center the cross-sectionof the ribs shows the gain to be 6 cm. (From R. LeFort, Revue de Chirurgie, Tome 53, 1917.)

markable monograph, made a very careful study of this method, to which he refers only as "l'incision intercostale combinée avec la section simple des cartilages costales, sus et sous jacente." He does not mention Spangaro's work or discuss the history of the procedure. He expresses a very favorable opinion of its practical application, as it gives more space than the resection of a rib followed by retraction. It gives a large working space when the ribs are retracted with a powerful rib stretcher (such as Willy Meyer's, Lilienthal's, or Tuffier's models). The effect of this incision combined with section of the cartilages close

to the sternum, forming a horizontal letter ⊢, is well seen in LeFort's comparative study of rib resection and this incision in Fig. 8 of LeFort's book. The incision may be prolonged from the sternum backward as far as the postaxillary line or even to the anterior edge of the scapula; or it may be made shorter for more superficial cardiopulmonary work. In one case, by prolonging the incision along the seventh intercostal space to the scapula, he was able to extract a projectile placed behind the inferior vena cava in proximity to the esophagus. He was also

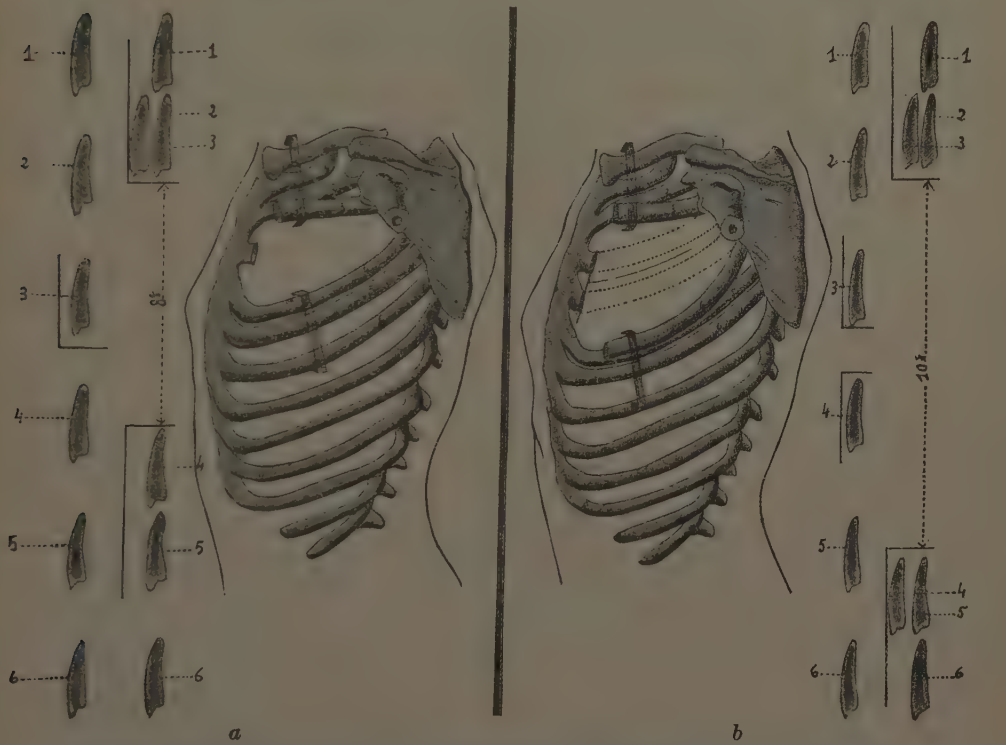

FIG. 325.—*a* SHOWS THAT BY SIMPLY DIVIDING THE FOURTH COSTAL CARTILAGE CLOSE TO THE STERNUM, WITHOUT RIB RESECTION, THE APERTURE OBTAINED BY SIMPLE INTERCOSTAL INCISION IS INCREASED BY FORCIBLE RETRACTION TO 8 CM. BY MERELY OVERLAPPING THE FOURTH OVER THE FIFTH RIB.

In this way all the space available by a rib resection is obtained with greater simplicity and less trauma. *b* shows that if, in addition, the third costal cartilage is divided, the aperture or breach in the thorax may attain as much as 9½ cm. Furthermore, the working space may be further increased to any desired dimension without resection by the simple division of additional costal cartilages, and retraction with powerful rib spreaders. (R. LeFort, Revue de Chirurgie, Tome 53, 1917.)

able to obtain a clear view of the dome of the diaphragm, the whole lateral surface of the heart, the inferior lobe of the lung, and the lower part of the mediastinum. Access to the heart and mediastinal organs can be obtained with greater or less advantage according to the intercostal space selected for the incision. Of all the transpleural methods, the Spangaro incision is still the best for emergencies, in thoracic wounds which involve the pleura and in which an actual lesion of the heart is still in doubt. This is particularly true of stab and punctured wounds

in the precordial region in which there is no definite *x*-ray localization possible. When the pleura is not open and there is doubt in the diagnosis the exploratory incisions which expose the pericardium without involving the pleura ("Voinitch's triangle of safety," see Vol. V of this treatise) are to be preferred. If the diagnosis of progressive hemopericardium proves positive, the exploratory incision can immediately be converted into a median abdominothoracic pericardiotomy, or the Duval-Barnsby operation, which will give the largest attainable access to the thoracic contents. This last procedure undoubtedly is best adapted to the suture of gunshot wounds and for the extraction of projectiles which have remained embedded in the heart. It is the method of election in all cases in which the diagnosis of the lesion and the presence of the projectile *in* the heart or in its immediate vicinity is made certain by the radiologic findings. This is particularly true of delayed or late extractions of projectiles from the heart in which multiple pericardial adhesions and unexpected complications are likely to require the largest working space obtainable.

Median Sternal Thoracotomy, Milton's Operation with Modifications.—The large lateral parasternal trap-door osteoplastic flap of Delorme, which is preferred by LeFort and others for heart operations, does not give ready access to the base of the heart or the great vessels at its root or its posterior surface without considerable manipulation, traction, torsion, or displacement of the organ. This disadvantage is common to all methods of costal resection, no matter how large, that open the thorax on either side of the sternum. The sternum is in the way. For this reason secondary supplementary resection of the sternum becomes necessary when it is discovered that the unilateral flap is insufficient to reach the base and posterior surface of the heart completely. It is in recognition of this failure to meet all the requirements that LeFort himself has resorted sometimes to a double hinged trap-door, one flap holding the divided rib sections, and the other, a total or partial transverse section of the sternum. The methods of Fontan, Terrier-Raymond, Marion, Morestin, Podrez, Rydygier, Cantas, *et al.*, are all intended to overcome the obstacle of the sternum in giving free access to the heart. Even Délorme, the father of the method, has advised a partial resection of the sternum if it is found that his external parasternal trap-door flap is inadequate to meet the requirements of the case. Therefore, a procedure that will give free access to all parts of the heart, including the auricles, posterior surface, and the great vessels at the root, without opening the pleura or injuring the internal mammary vessels, is highly desirable, the demand for such a procedure became more frequent as foreign bodies multiplied in consequence of the World War. This has led to a reconsideration of the advantages of the mediosternal route which Milton, of Cairo, originally proposed and put into practice in 1897. By this method the entire sternum was divided longitudinally from the suprasternal notch to the ensiform and gave a large view into the anterior mediastinum by retraction; but this view was insufficient for such

manipulations as would be required in cardiac surgery. The mere division of the sternum (median sternotomy) may do well as a decompressive measure for the relief of intrathoracic tension due to overcrowding of the thoracic organs by the presence of mediastinal tumors, aneurysms, etc., but it is not sufficient for free cardiac manipulation. To obtain a good working space the sternum must be cross-sectioned on a line with the third costal cartilage, as it is only in this way that the two sternal halves can be retracted and spread open like a book, with the costal cartilages acting as hinges. This is what Rehn fully realized when he modified the total median sternotomy of Milton by making the additional transverse sections above mentioned. Furthermore, the total division of the sternum including the manubrium is an impediment to retraction on account of the rigidity of the sterno-clavicular joints. Rhen warmly recommends this method above all others in which the pleura is not involved: "It gives the greatest, if not absolute, safety to the pleura. It also gives us the possibility of immediately controlling the heart, in that we can reach both venæ cavæ and lessen the supply to the heart, as desired." In 1914 he had made use of this method six times, and it had always proved satisfactory. He advocates this method for the following conditions: 1, In all heart wounds; 2, in the freeing of the heart from (*a*) pericardial adhesions of childhood, (*b*) in sclerogenic mediastinopericarditis, (*c*) certain malformations of the chest, (*d*) in resection of the pericardium (pericardiectomy for cardiosymphysis) followed by plastic operation with a fat flap (to prevent the recurrence of a synechia), (*e*) in chronic pericardial tuberculosis. He includes the reports of two successful operations for gunshot wounds of the heart, both of the right ventricle, in one of which the bleeding had to be controlled by digital compression of the cavæ while suturing the wounds. He also operated successfully in this way for decompression in cardiac dilatation following pericardial adhesions. I have also performed a complete median sternotomy for thoracic decompression in a case of mediastinal sarcoma (October 13, 1916), and found that the procedure was quite simple and gave ample room for exploration.

This operation, as independently devised and practised by Pierre Duval and Barnsby, has been modified by the addition of details of vital importance to the technic. In a recent paper, in collaboration with Henry and Pierre Barasty, Duval described the operation as he now performs it under the title of "Median Thoraco-abdominal Pericardiotomy":

"A median incision, extending from the level of the third costal cartilage to a point in the linea alba, midway between the tip of the xyphoid cartilage and the umbilicus. After cutting through the skin to the sternum, the incision is carried through the abdominal aponeurosis and between the recti down to, but *not through*, the peritoneum.

"The upper insertions of both recti are detached from the edge of the ensiform cartilage, exactly through the median line and the posterior surface of the ensiform, the attachments of the diaphragm also being cut away from the cartilage. Two fingers of the left hand are inserted and pushed from below upward and behind the

xyphoid, and then behind the sternum up to the level of the third costal cartilage, the fingers always closely following the posterior surface of the bone.

"In this way the pericardium is detached from the retrosternal connective tissue by separating the fingers slightly, they push and crowd the two pleural culdesacs away from the midline and laterally to the under surface of the costal cartilages. This maneuver is simple and easy.

"*Longitudinal Sternal Section.*—The sternum is then split in the midline with a large chisel [Hudson's large sternotome or costotome does better and quicker work], beginning from the tip of the xyphoid and ending on a level with the third costal cartilage. At this level a transverse section of the sternum is made, leaving the manubrium attached to the clavicle and to the first and second cartilages. The two halves of the sternum are now spread open and lifted out, and bent over with retractors or strong hooks, care being taken not to fracture the cartilages. The mere lifting up and spreading of the two halves of the sternum with an outward bending of the yielding costal cartilages will suffice to give a good working space in the mediastinum. Through this large vertical space the pleural culdesacs and pericardium are recognized, displaced, and detached from the thoracic wall with gentle gauze sponge pressure to avoid any tearing of the pleuræ.

"*Laparotomy* and *Pericardiotomy.*—The peritoneum is now opened in the midline. By inclining the incision a little toward the left and immediately along the insertion of the diaphragm to the chest wall the pleuræ will be seen to diverge, leaving a very considerable and safe interspace between them. The pericardium is now held up with two forceps and the fold thus lifted up is divided in the midline. Each edge of the pericardial incision is now held in a forceps as the heart is exposed.

"With sharp, straight, but blunt-pointed scissors the pericardium is now split its full length to the root of the great vessels. The pleural culdesacs are now safe and need not be considered.

"*Section of the Diaphragm.*—Between the pericardial and peritoneal sacs the diaphragm still remains as a horizontal partition holding the two halves of the divided xyphoid in place. The scissors are again introduced and the diaphragm is divided up to the level of the suspensory ligament. While this maneuver is being executed the heart is gently protected by the hand of an assistant. The hooks or retractors then pull the sternal halves apart, and by lifting them up and bending them outward upon their cartilaginous attachments they widely open the retrosternal space. It is like opening a book, exhibiting the heart with the great vessels at its base in full view before the operator. The ventricles, auricles, aorta, and venæ cavæ, anterior and posterior surfaces of the heart are thus made more easily accessible to any manipulation without requiring exteriorization, traction, or torsion of the organ. The two hands of the operator may execute any maneuvers or procedures that may be required, with the heart in place.

"After the suture of a wound or extraction of a projectile the operation is concluded by the suture of the diaphragm, then of the abdominal incision and of the posterior wall of the pericardium. The sternal halves are replaced and held in contact by deep aponeurotic sutures without bone suture support. Finally a continuous or interrupted suture closes the skin" (Fig. 326).

This technic is not based solely upon cadaveric studies. Duval's mediosternotomy has been applied at least three times, and once for the extraction of a missile from the pericardial segment of the inferior vena cava. It gives ready access to the inferior vena cava through the pericardial sac, and permits the extraction of the bullet from the cava by an incision made at its very junction with the auricle.

"No trap-door flap or any of the classical intercostal incisions have ever given us so free and easy a working space. This 'median thoracoabdominal pericardiotomy' appears to me to be the elective procedure in all operations on the heart and great vessels which are included in the pericardial sac" (Duval).

Two points of importance are to be noted as original in Duval's operation. First, the abdominal section with detachment of the insertions of the recti to the xyphoid cartilage at the costal arch, and, second, the free division of the diaphragm in the middle line up to the

pericardium, which, in turn, is split open to its upper limit at its reflection over the great vessels. This abdominodiaphragmatic feature of

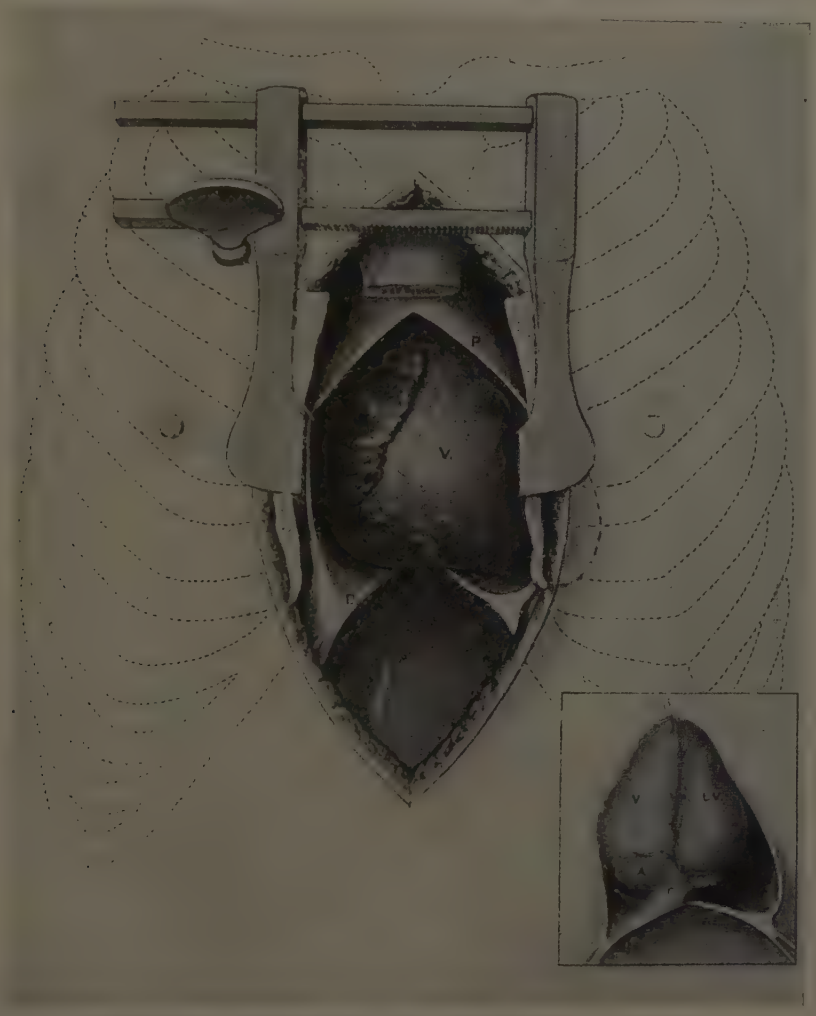

FIG. 326.—THE DUVAL-BARASTY *Median Thoraco-abdominal Pericardiotomy.*

The drawing was made from an operation performed on a young adult male cadaver: *P*, Cut edge of pericardium; *D*, cut edge of diaphragm; *A*, right auricle; *V*, right ventricle. In this case the halves of the sternum were drawn apart for a space of 3 inches. During this maneuver they and the attached cartilages moved forward as well as outward. The retractor has to be very powerful.

Small insert drawing on the right: *V*, Right ventricle; *LV*, left ventricle; *A*, right auricle; *LA*, left auricle; *C*, inferior vena cava extending from diaphragm to right auricle. A suture has been passed through the apex of the heart and by it the organ has been drawn forward and upward. In this way the whole posterior surface of the heart is exposed. (From Ballance's "Surgery of the Heart"; Bradshaw lecture, Dec. 11, 1920, Macmillan, London.)

[The first operation performed by this procedure was reported by P. Duval and H. Barnsby to the Societé de Chirurgie on Jan. 26, 1918 (see Bull. et Mém. Soc. de Chirurgie, T. xliv, No. 23, July 2, 1918). An extremely movable pointed bullet was removed from the vena cava inferior at its junction with the right auricle. The operation was successful in every way and was followed by complete recovery.—R. M.]

the operation is necessary in order to obtain a retraction of the sternal halves on parallel lines; if this is not done (as in Rehn's operation) the

opening obtained by division of the sternum assumes a triangular form, with the apex at the xyphoid, which seriously interferes with the view and the manipulations in the mediastinum. Two other points are to be observed: first, in making the cross-section of the sternum on a level with the third rib, the incision is not to be carried too far beyond the bone for fear of injuring the internal mammary arteries; second, care must be taken in lifting and bending the sternal flaps not to break the ribs, as this might lead to a perforation of the pleuræ. If the flaps are lifted and bent upward and outward the cartilages will yield without breaking, so that when the operation is completed, the sternal halves will fall readily into normal position.

The chief and only objection that can be made against this procedure is its magnitude; but this objection is more apparent than real. It is certainly not a greater trauma than is involved in making a large trap-door osteoplastic flap which at once creates a pneumothorax, and it is certainly less bloody, as the section of the tissues is all made in the midline. The three patients operated by this method (Duval and Barnsby, Barbier and Gujon, and H. Rouvillois) all recovered, and in each it would seem that the manipulations required for the extraction of the projectiles could not have been effected as safely, to say the least, by any other procedure.

These three cases are so unique and instructive in various ways that each one should be read in detail.

The third case (Rouvillois) is notable because of the extraordinary initial tolerance of the heart to the missile, and from the fact that four and a half years elapsed between the injury and the operation. It shows that, notwithstanding the comparative insignificance and benignity of the initial symptoms, these gave no clue to the gravity of the cardiovascular asthenia which subsequently developed. This case also shows that the presence of the bullet, though perfectly encysted in the heart walls, may be the sole cause of serious cardiac disturbances independent of secondary complications. It also shows that even experts in radiology (like the rest of us) are fallible (which is nothing new). In this patient several unnecessary operations were performed under the mistaken impression that the bullet was lying outside of the heart.

Late or Delayed Extraction of Cardiopericardial Projectiles by the Method of Petit de la Villeon.—In sharp and striking contrast with the methods which stand for a "wide-open door and plenty of light" in the thorax for the treatment of heart wounds and the extraction of cardiac projectiles, we find the method of Petit de la Villéon. The peculiarity of this method is that it searches for intrathoracic projectiles under the fluoroscopic screen and extracts them through the smallest buttonhole openings. The openings are made in the intercostal spaces after a careful localization of the projectile, and with this in constant view, a long blunt-pointed forceps follows it wherever it may be, and extracts it. This method, which is known as the method of the "forceps under screen," is one of the most extraordinary and sensational developments of the war's experience.

de la Villéon first began to apply his method* early in the war in the extraction of projectiles lost in the extremities. His success was so great that he tried it in the chest for the removal of foreign bodies in the lung and mediastinum. This was done for the first time in October 27, 1915 with remarkable success, not only by the distinguished originator himself, but by a large number of surgeons who have followed in his footsteps. This emboldened de la Villéon to attempt the extraction of bullets and other foreign bodies from the heart and pericardium.

On May 28, 1919 he reported the extraction of 14 projectiles from the cardiopericardial or cardiopulmonary area. All of these patients were relieved of their projectiles and were up and about in an astonishingly short time (three to five days) after the operation.

In reply to the numerous criticisms bearing on the uncertain and adventurous nature of this procedure he explained at the Societé de Chirurgie what he regarded as the limitations of the method in its applications to cardiopericardial projectiles. Only missiles attached to the surface of the heart could be attacked by this method. He would not dream of removing any projectiles which penetrated the heart cavities and he would not attempt the extraction of bodies embedded in the auricles or right ventricle because he realized full well the dangers of hemorrhage from dislodging such bodies. The "permissible zone" of attack was the pericardium, the thick wall of the left ventricle, and the thicker cone of the apex.

It is easy to understand that such a procedure could find no application in the surgery of the heart, no matter how useful in the hands of an expert the method has proved to be in the lung and other less vital localities. It is not surprising that on several occasions the procedure as applied to the heart, even in the restricted way in which de la Villéon applies it, should have been received with scant favor by the most representative French surgeons (Pierre Duval, Broca, Tuffier, LaPointe, Hartmann, *et al.*). The consensus of opinion, as formulated at the close of the discussion, was summed up by Hartmann, who stated that "no matter how satisfactory this method had proved to be in the lung and in other parts of the body, it had no place in the surgery of the heart, and should not be employed for the removal of cardiac projectiles."

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* After about 4000 projectiles had been removed from various parts of the body by this method. Quoted by Le Conte, Ann. of Surg., July, 1919.

THE RADIOLOGIC PECULIARITIES OF PROJECTILES IN THE HEART

It is now admitted that *radioscopy* by the way of the fluoroscopic screen, and not *radiography*, is the proper way of utilizing the *x*-ray for cardiodiagnostic work. It should be remembered that many mobile bodies may leave no impression upon a radiographic plate on account of the rapidity of their oscillations, unless the radiologist is prepared to apply instantaneous radiography, as has been done by Lédoux-Lébard.

When a foreign body, localized in the cardiac shadow, follows the movements of the heart and is not influenced by those of respiration, it is logical to infer that that body is in the heart or is attached to it. An extracardiac projectile in close proximity to it may move also with impulses which are synchronous with the heart-beat. The diagnosis is then one of *probability and not certainty*. It is of the highest interest to determine if the foreign bodies are free and movable in the heart cavities, as their extraction involves far greater risk to the patient. Fortunately, radiologists have furnished us a number of facts by which the differential diagnosis between the *fixed* intracardiac and the *mobile* bodies can be reasonably and often quite strikingly established. Not only can the presence of a free and mobile body in the heart chambers be made certain, but the peculiar movements which characterize some of these bodies suggest, if they do not actually differentiate, the particular cavities in which they reside.

Auricular Cavities.—Laurent, of Brussels, asserts that a free, movable body lodged in the *right auricle* is animated and distinguished by its "whirling" (en *tourbillon*), "corkscrew," "spiral," "gimlet," "drill-like" (en *vrille*) movements.

M. Barnet, the radiologist who especially studied Vouzelle's case, states that when the bullet was seen in the heart shadow it exhibited extreme and incessant motion and was agitated in a vortex, like a ball in a jingle ("en balle de grelot"). The displacement which it would undergo with every cardiac impulse was effected with amplitude and rapidity, but it was only by a most minute fluoroscopic examination that the missile could be seen, and then for a very brief instant, when it reached the two extremes of its course. The extremes of the oscillation were 4 cm. apart. At the operation the projectile was found in the right auricle and was displaced into the right ventricle by the surgical manipulations, which had to be interrupted and finally abandoned, without extraction of the missile, on account of the syncope induced by each attempt to grasp the heart. The patient died four days after the attempt in a paroxysm of suffocation.

Lédoux-Lébard based his diagnosis of a projectile in the *right auricle* on the motion of the foreign body which performed "whirling" movements in an elliptic orbit with a major axis of 2 cm. This opinion, however, was based on other data which, taken together, established a diagnosis, confirmed by operation.

In Ascoli's case the foreign body, a shrapnel ball, migrating into the right auricle by way of the vena cava made rhythmic, pendulum-like movements of about 2 to 3 cm. excursion synchronizing with the con-

tractions of the auricle. This pendulum swing was interrupted at intervals in the middle. At the internal limit of its course the projectile was caught up in a whirlpool, which carried it back to its starting-point.

Ventricles.—Lobligeois detected a shrapnel ball in the left ventricle and watched its motion. The ball at the end of the diastole rested on the left lower border of the heart near the apex. With the beginning of the systole it moved from left to right until it struck the interventricular septum; following this it would roll upward in a vertical line to the highest level of the ventricle, but always along the septum. This marked the end of the systole. For an instant it rested here immovable, then it gradually moved downward and from right to left during the diastole, to reach its resting position near the apex, ready to begin a new cycle with the next contraction.

The bullet in this way described in its course a rectangular triangle with its right angle rounded off. Lobligeois contrasts the rapidity with which the projectile sped (during the systole) over the two adjacent borders of the right angle with its slowness (during diastole) along the line of the hypotenuse.

Missiles in the myocardium are illustrated by a bullet buried in the anterior wall of the right ventricle in the heart of an aviator observed by MM. Désplas and Chévalier. Operation was impracticable. Autopsy. A similar case, in which a piece of shell was buried in the right ventricle. Extraction, recovery (Dujarier). In these cases the projectiles move with the heart muscle itself. The movements are characteristic and invariable. One motion is vertical, up and down, of short excursion, and the other, horizontal, from right to left. These movements being definite and invariable, suggest, when seen, an intramural or fixed body which is moved by the contractions of the myocardium to which it is attached. The movements imparted to a mobile body free in the cavity are quite different, as these missiles obey the impulses and force of the blood-currents as well as the configuration of the heart chambers in which they play.

Escande and Brocq reported two cases of unmistakable localization of projectile in the heart walls which were not operated upon, but furnished very interesting data.

In the first case the bullet was seen inside the cardiac shadow. The projectile was animated by regular oscillations synchronous with the cardiac contractions. The base of the bullet had slight mobility. The point presented regular up-and-down movements with each contraction of the heart, and described the arc of a circle, with a chord of $\frac{1}{2}$ to 1 cm., moving on a fixed point which is the base of the projectile. The pulmonary inspirations diminished the amplitude of these oscillations without suppressing them. The final conclusion was definitely stated as follows: "A pointed rifle bullet embedded in the myocardium, lying in the left and lower part of the interventricular septum, with the point of the bullet projecting into the left ventricle." The patient was observed for twenty-three months and, as tolerance was established, no operation was performed.

In the second case, reported by the same authors, a small splinter of shell had entered the heart and was embedded in the apex and was well tolerated. The patient was observed for nine months, and discharged, as the lesion left no symptoms or any physical signs of functional disability.

Robineau thus summarizes the radiologic evidence: The *first sign* is obtained by the pulsating movements of the projectiles. In the lung, even at a great distance from the heart and the great vessels, projectiles often pulsate; the most frequent cause for these pulsations lies in the expansion of the lungs by the systolic inflow which is registered by the metallic body, if the lung has contracted adhesions at a distance. Projectiles very near the heart, but not included in it (pericardium, etc.), are equally pulsatile. In every case the pulsations are simple and consist in a rhythmic displacement of feeble amplitude; they give the impression that they have been lifted by an arterial wave.

The pulsatile movements of the projectiles *in the myocardium* vary according to their seat; they have a great amplitude; at first, they appear irregular; later, a movement of torsion is recognized from right to left, then a creeping movement (*"movement de reptation"*), then a zig-zag. The trajectory is not necessarily rectilinear, and at times a short run may be distinguished in one direction, and a long one in another. Again, the displacements are brusque and rapid, giving the impression of the quick contraction of the cardiac muscle.

These manifestations appear to be sufficient to affirm the inclusion of a projectile in the myocardium. Can the radiologist tell by the measurement of depth of penetration in the heart wall whether the projectile is nearer the endocardium than the surface? This is admitted by all to be practically impossible (Lédoux-Lébard and Contremoulins). All that can be affirmed with certainty at present is that the missile is included or embedded in the myocardium, which differentiates this from the intracavital bodies.

From all this it would appear, in a general way, that the movements of projectiles or floating bodies lying free in the *auricles* are of a "whirling" or "swirling" character, while those in the *ventricle* are rapidly oscillating, but are more definitely linear or pendulum-like in character.

Evidently a new and most promising field for accurate differential localization and diagnosis is opened to radiologists by these recent revelations.

The only supplementary information that is required to complete this extraordinary advance in diagnosis is the electrocardiogrammatic study of the heart by Lewis' method, before and after the operation, to determine the physiologic and functional working of the injured heart.

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THE PROGNOSIS AND INDICATIONS FOR THE LATE OR DELAYED EXTRACTION OF RETAINED PROJECTILES AND OTHER FOREIGN BODIES IN THE HEART

The literature of the war bearing on the extraction of foreign bodies lodged in the heart has furnished many new and important documents and statistics relating to the prognosis and treatment of these grave and often perplexing injuries. Among these papers probably the most valuable for the purpose are the essays and reports published in the Bulletins et Mémoires de la Société de Chirurgie de Paris, the Bulletin de L'Academie de Medecine, the Revue de Chirurgie, the Journal de Chirurgie, the Presse Médicale, and Paris Chirurgical (for 1914–19), which contain the valuable contributions of Beaussenat, Délorme, René LeFort, Pierre Duval, Paul and Pierre Delbet, Esconde and Brocq, Constantini and Vigot, Petit de la Villéon, and others, too numerous to mention, whose experiences reflect most creditably upon the enterprise and ability of the French surgeons and radiologists, who have been the leaders in this branch of surgery during the war.

In England the papers of Bland-Sutton (The Lancet, May 10, 1919) and especially Ballance's Bradshaw Lecture (The Lancet, January 3, 1920) are prominent and most interesting as embodying the thought and the collective experiences of British surgery.

In Italy the excellent recent monograph of F. Rossi (Le Ferite del torace d' arma di fuoco, Milano, 1919) presents a most thorough review of the literature and is invaluable for reference.

In German literature Kukula, of Prague (Medizin. Klin., 1917, No. 33); Rehn (Bruns' Beiträg. klin. Chir., 1917, Bd. 106, H. 5); Freund and Caspersohn (Münch. med. Woch. No. 35, 1915) are also valuable, among the many individual reports, in gaining an insight into German experiences and opinions.

From a review of this literature we gather that opinions are divided even among the most experienced operators as to the proper indications for the extraction of projectiles in the late, delayed posttraumatic cases.

For instance, Freund and Capersohn affirm that the frequent absence of symptoms should not be in favor of passive abstentionist policy, or a "watchful waiting" attitude. Scars in the myocardium are dangerous. The walls of the heart may degenerate and yield at the point of penetration, and fatal intrapericardiac hemorrhage may ensue. The menace of thrombosis and embolism is always present. The argument of these writers and of others is in favor of an energetic surgical intervention.

Kukula (1917), in his study of 19 cases, expresses the opinion that when projectiles are embedded in the myocardium, systematic or routine removal of the projectile is not indicated unless grave cardiac disturbances menace life. When the projectiles are in the heart chambers he favors the extraction of the projectile and recommends the operation, but leaves the decision to the patient. Muhlsam, on the other hand, states that the operative treatment of gunshot wounds of the heart

with retained projectiles constitutes one of the most serious errors of the new surgery. Dieterich and Hartmann lay stress upon repeated syncopal attacks and violent anginose pains as signals for surgical action.

Colonel Gray found arhythmia a sufficient indication for the extraction of a projectile in the heart.

Délorme (September, 1917) in his learned and critical discussion of the subject distinguishes, with good reason, between the indications furnished by (*a*) parietal or parietocavital projectiles, and (*b*) cavital projectiles. He groups the patients with retained cardiac missiles into three classes:

1. The patient suffering with grave symptoms and manifestations which constantly menace life; there may be a state of anguish and cardiac distress or suffocating crises which are precipitated by the least movement, or he may be troubled with persistent pains during sleep, there are attacks of violent palpitation, tachycardia, or even a delirium cordis (Couteaud and Béllot) or heart-block (Rothfuchs). Here there can be no hesitation. The operation is indicated whether the projectiles be penetrating or not—parietal or intracavital.

2. The symptoms are less alarming; the manifestations are annoying and even painful, but tolerable; the only fear is that the foreign body may give rise to disturbances in the future by migration or other means. To prevent these would be the chief reason for an operation, and this would be largely prophylactic. As these possible complications are more or less uncertain and the foreign body may become encysted, fixed, and dormant, there is reason to wait and abstain from interference.

Brémond and Morian conclude, very sensibly, that the mere diagnosis of a projectile in the heart does not justify an operation, which is always of a grave character and may be fatal in its consequence. The operation should never subject the patient to as great a risk as the condition which it aims to cure. The characteristics of the projectile (its nature, size, form, etc.), its exact localization, and, above all, the most careful analysis of the clinical symptoms should serve as a guide to the surgical indications.

3. The patient is troubled with mild symptoms, but the radiologic diagnosis makes it plain that the projectile is intracardiac; it may be free in an auricle or a ventricle. It may have been discovered by accident. These cases are becoming numerous. They are the latent cases. In Lobligeois' case, for instance, the patient carried a shrapnel ball in his right ventricle for months; it was movable and yet he complained of no serious symptoms and no operation was performed.

If the foreign body is smooth it is not likely to irritate the endocardium, or, if it shows no tendency to move, it may not be dislodged as an embolus or excite cardiac thrombosis with secondary emboli, why disturb it? But who can affirm that the body, notwithstanding its comparative tolerance by the heart, may not some day be ejected under certain conditions, and then cause death quickly by plugging either the pulmonary artery, if in the right ventricle or auricle, or by blocking some large branch of the abdominal aorta or the aorta itself, if it is in

the left ventricle? If the body is smooth, spheric, it is of safer prognosis, but if the body is irregular in form (fragments of shell) the danger of secondary disturbance in the heart is not to be minimized, and an operation would be justifiable (Délorme).

On the other hand, the fact remains that the foreign bodies are often so well tolerated as to mislead our judgment, or what may be tolerated for months and years, may suddenly be transformed into a very intolerant, serious, and fatal condition. It is well to remember, as Paul Delbet has shown, that in 45 cases in which pointed, cutting, irritating bodies entered the heart, only 4 cases survived for years without some serious complications. In 70 gunshot wounds in which the projectiles were known to be in the heart cavities, there were only 12 real cures without operation (Paul Delbet).

Délorme supplements his previous report of 17 cases gathered from recent French military sources by adding a series of new cases which increases the list of French cardiotomies for foreign bodies up to September, 1917 to 25 cases. Of the first 17 cases which were reported in detail he found that ten of the missiles had been removed from the right ventricle, three from the right auricle, two from the left ventricle, and one from the left auricle. The result in 13 cases was surprising: 10 recoveries and 3 deaths (76.1 per cent. recoveries). René LeFort states that he had removed eleven foreign bodies from the heart in the course of nine operations; in two cases from the heart cavities with only one death; all the others were cured.

The gross comparative statistics of the delayed and late operations for cardiac projectiles, including the operative and non-operative cases, are summed up to December, 1918 by Pierre Duval, who has gathered much of his statistical material from Rossi's monograph. The total number of reported war projectiles in the heart up to 1918 is 62*:

Parietal or mural projectiles, 39 cases.

Operated on, 16; recoveries, 14; deaths, 2.

Not operated on, 23; recoveries, 23; deaths 0.

Projectiles retained in the heart cavities (*intracavital* projectiles), 23 cases:

Operated on, 10; recoveries, 7; deaths, 3.

Not operated on, 13; recoveries, 12; deaths, 1.

Judging by these statistics, it plainly follows that non-intervention should be the rule. Evidently, however, the indications for operation cannot be arrived at by mere statistics.

In dealing with the intracavital bodies there is no question that bodies originally movable, in the course of time may become fixed and movable as shown by repeated *x*-ray examinations (in Schultze's case the bullet became fixed six months after the injury. In Finzi's case the missile became fixed seven days after it had been seen moving freely in

* These figures do not include the cases in which the projectiles have found their way into the heart cavities through the peripheral or extracardiac avenues of the circulation. Of this group, Duval finds 12 cases, with 9 deaths. Neither does he include de la Villéon's cases.

the cavity). On the other hand, there are other cases which prove clearly that the missiles may be dislodged from the heart by the blood-stream, either *with* the current (progressive embolism), or *against* it (retrograde embolism).

We have quoted a number of these cases in discussing the migration of projectiles, and we have seen that in the right heart retrograde or paradoxic embolism can be reproduced experimentally, and is also clinically illustrated by several striking cases. The progressive migration through the left cavity of the heart into the aorta and its branches is also shown by many cases. The migration of projectiles which are primarily cardiac is much less frequently observed than in those which enter the heart through the peripheral channels of the circulation (12 cases—9 deaths).

Again, extracavital projectiles are often borne with extraordinary tolerance. Apart from the many illustrations supplied by the older literature, many new instances could be quoted out of recent experiences which confirm this generally admitted fact.

Duval, after reviewing the evidence, concludes that he would not hesitate to advise the extraction of an intracavital projectile if for no other reason than to avoid the dangers of embolism.

The possible fixation of the projectile in the auricular or ventricular walls, the remarkable tolerance exhibited by the heart for some forms of foreign bodies, the non-irritating quality of the smooth, round, polished projectiles do not eliminate the possibility of secondary complications, and offer no security to the patient as long as he carries the bullet in his heart. In these uncertainties the patient must exercise his own judgment after all the risks, with and without operation, are explained to him.

Parietal or Intramural Bodies.—In these cases the condition is quite different from those exhibited when free movable bodies are lying loose in the cavity, and the indication for operative interference is still more doubtful and perplexing. The symptomatology in many of these cases is practically negative and suggests no reason for interference. Rossi, in a study of 69 cases of this class, observes that in 37 of these there were no symptoms that would justify an operation.

Against the judgment of some authors, who regard the presence of severe precordial pain and anginose crises as a positive call for interference, we find other observers who report the spontaneous disappearance (without operation) of these crises and anginose pains. Rossi shows in his statistics that 23 cases of foreign bodies embedded in the heart all recovered without exception and without recourse to operation. It would seem, also, after reading the history of some of these patients that the complaints made by them are rather the result of their temperamental or psychic idiosyncracies, than of the presence of a projectile in the walls of the heart.

Projectiles of small caliber or small foreign bodies are particularly well tolerated by the myocardium. If one of these bodies is brought in contact with the nerve-regulating centers of the heart (bundle of His,

etc.) experience shows that it will give rise to serious circulatory disturbances. But the extreme sensibility of these centers would lead us to expect that their injury or permanent irritation would give rise to immediate or rapidly fatal consequences. But even these have survived, as shown in the cases of heart-block reported elsewhere.

Again, functional disturbances in the heart action often result from pericardial adhesions and cardiosymphysis. In 18 cases operated on Rossi finds this condition existing in 7; it is, therefore, one of the complications and sequels of cardiac traumatism which the mere extraction of a projectile could not be expected to relieve. It is possible that when cardiopericardial symphysis exists as a sequel to a cardiac injury, relief may be obtained by cardiolysis (Brauer), *i. e.*, the resection of the osseous framework in the precordial region, which may prevent the tug on the heart by the pericardium and the unyielding chest wall.

However discrepant the views that are entertained by different surgeons in regard to the indications for or against intervention in this group of cases, the fact remains that in the presence of fixed, parietal projectiles, the statistics show (Rossi, Duval) that in 16 parietal projectiles that were extracted by operation, 14 recovered and 2 died (Bichat and Couteaud, Belot), and that in 23 parietal projectiles that were *not* operated on, the 23 survived and recovered.

From all this it would appear that, notwithstanding all the advances of thoracic surgery, there are no rules that guide the surgeon in the prognosis with absolute certainty, and that indications for operation must be based upon the condition of the patient and the degree and duration of his disability. *It is only when life is threatened* and the patient thoroughly understands his danger as well as risks of an operation that this can be undertaken.

If an operation is decided upon, it is then that the advances and the new knowledge of the technic acquired by the experience of the late war will, no doubt, prove to be a valuable acquisition.

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Part II

Military Surgery of the Blood-vessels

The peculiarities of gunshot injuries of the blood-vessels caused by modern military projectiles have been fully considered in Volume IV. These may be briefly summed up in regard to the effects of the small cylindroconoidal, ogival, and hard-pointed, jacketed, high-velocity projectile of the modern military rifle, as follows: (1) Comparatively small *primary* hemorrhage, with tendency to spontaneous hemostasis, in spite of extensive damage to the blood-vessel; (2) frequent occurrence of

secondary hemorrhage; (3) tendency to through-and-through perforation with narrow tunneled tracts; (4) aseptic course; (5) frequent occurrence of traumatic aneurysms involving the artery, but more often both artery and vein (arterial and arteriovenous aneurysms); (6) explosive effects in the tissues, especially in the closed cavities, when these are struck at short range.

The late World War has only confirmed what we knew of these characteristics by the experiences of the previous wars, and since the universal adoption of the modern rifle by the armies of the world, and especially by the actual experience of the Boer and subsequent wars, down to 1914, which gave large opportunities for the study of the effects of the missiles of the small calibered army rifle of high velocity upon the blood-vessels. But the experience of the late war differs radically from any previous wars in the introduction of the pointed bullet and vast preponderance of artillery warfare, in the use of high explosives, in the shape of shells, bombs, hand grenades, shrapnel, with the consequent effect upon the range, weight, velocity, size, and number of the fragments of shells or contained projectiles, thus creating an endless variety of atypic wounds, the characteristics of which are just the reverse of the smooth, narrow, tunneled, clean tracts of the standardized rifle bullets at long ranges. In this way the classical concept of gunshot wounds of the blood-vessels, and, for that matter, of the war traumata of all the tissues, has been revolutionized. We have reverted to the old type of injuries in which the incised, contused, and lacerated wounds with immense destruction of the tissues, coincidentally with retention of foreign bodies and the introduction of septic material of the most virulent type, have been the dominant characteristics. In this way the old dictum that gunshot wounds are to be regarded as clean and practically sterile wounds has been reversed; we have learned that all gunshot wounds must be regarded primarily as contaminated and septic as the keynote of the present treatment. Therefore the distinction between the effect of the modern pointed army bullets, whether from rifle or machine guns, and the wounds caused by fragments or missiles from explosive shells is fraught with infinitely broader and graver significance to the surgeon than was ever recognized in the previous history of military surgery.

In one respect the surgery of the blood-vessels has profited in the recognition, early in the war, of their thoroughly septic and virulent character. When this fundamental fact was recognized and appreciated, the conclusion, which was epochal in its importance, though tardily arrived at—*i. e.*, that it was only by prompt immediate intervention (within the first twelve to eighteen hours), in the incubation period of infection, or what is now designated as the "period of contamination,"—that effective results in the prophylaxis of sepsis could be obtained. But this was not all. Apart from the removal of foreign bodies, retained missiles, clothing, and other foreign matter, it was found necessary not only to extirpate all the contaminated and devitalized tissues, but a systematic dissection and excision of the wound and its

contents, thereby constituting the practice which is summed up in the now classical French word "débridement." This practice, forced upon surgery by the exigencies of the war, is one of its crowning achievements. In this way, and only in this way, have the disastrous effects of the septic gunshot wounds of the blood-vessels been prevented. By securing the mechanical sterilization of the wound in this prophylactic way the surgeon has eliminated from the traumatology of the blood-vessels some of its most pernicious attributes—secondary hemorrhage, which inevitably follows infection, suppuration and sloughing, and, also, by minimizing the tendency to excessive thrombosis and embolism in the blood-vessels with their necrotizing influence. In this respect, and apart from the advances made in controlling infection and septic processes when fully established by the application of more effective germicidal agents and by a more intelligent understanding of the natural defenses of the tissues, the experiences of the World War are revolutionary and will remain for all time as the crowning and most enduring achievement of surgery in this great conflict.

But apart from these great fundamental lessons which have improved the treatment of vascular injuries in common with other war wounds, the progress of vascular surgery has been influenced in a more direct way by the vast and unparalled opportunities offered for the observation and study of vascular lesions, their evolution, and their treatment. This has yielded information in many directions, *e. g.:*

(1) In a more accurate knowledge of the pathologic anatomy and physiology of vascular injuries, especially in that which relates to the wounds inflicted by atypical, irregular projectiles; (2) in a closer study of the early signs and symptoms by which these injuries can be detected; (3) in a better knowledge of the part played by the peripheral vasomotor nervous system on the blood-vessels; (4) in the hitherto unappreciated value of the auscultatory signs, both local, at the seat of the injury, and over the heart and thoracic centers of the circulation; (5) in a more accurate knowledge of the evolution of the primary injury to its secondary and terminal stages, viz., aneurysm; (6) in a better knowledge of the effects of the obliteration of the maimed vessels upon the dependent parts and upon more accurate methods of recognizing these effects; (7) in testing the efficiency of the peripheral and collateral circulation after the obliteration of the maimed vessels; (8) in a better knowledge of the structure, architecture, and anatomic types of arterial and arteriovenous aneurysms in their relation to the vessels and to primary injuries; (9) in a better opportunity to compare the various modes of treatment of these injuries by either the obliterative ligature or the conservative suture which aims at the preservation of the numerous channels of the circulation, and by other conservative methods applied with the same object in view. In this respect the methods adopted by the surgeons of the different belligerent armies have offered sharper contrasts than in any previous war; (10) in a great improvement in the means of detecting and extracting foreign bodies retained in the blood-vessels and especially the heart—in which vascular surgery has

profited in common with other departments of surgery through the unparalleled utilization of radiology as in no other war.

INCIDENCE AND DISTRIBUTION OF GUNSHOT INJURIES OF THE BLOOD-VESSELS

The relative proportion of vascular injuries among the wounded who survive long enough to reach the ambulances and first-aid posts cannot be determined at present, and we can only gather impressions from a few scattered reports from individual surgeons. From the few data available we can conservatively estimate that the number of gunshot wounds of the large blood-vessels that reach the surgeon in the first posts of relief fluctuates between 20 and 25 per cent. of the wounded.

Some idea of the frequency and importance of these injuries is gathered from the fact that in a single British casualty clearing station during the early days of the first battle of the Somme there were 277 wounds of individual vessels which required special treatment. Another view of the frequency of vascular injuries is afforded by the great number of traumatic aneurysms treated at the home hospitals of the various belligerents. Thus Makins has compiled 523 of these war aneurysms from various British hospitals, chiefly in London. The Bulletin of the Paris Société de Chirurgie, from 1914 to 1919 inclusive, fairly teems with reports and essays of individual operations. Salomon estimates from German sources that fully 1400 traumatic war aneurysms had been operated on in Germany up to the time of his report in 1918. Zahradnicky collected 405 traumatic aneurysms based upon the reports of 45 Austro-Hungarian and German operators, including 51 that came under his personal observation. Subbotich, reporting the combined Serbian experiences during the Balkan Wars, 1912–13, and the World War, 1914–15, collected the statistics of 169 traumatic aneurysms, including 64 personal observations.

In the Balkan campaigns of 1912 to 1913 whenever any statistics are given these cases represent from 1 to $2\frac{1}{2}$ per cent. of the wounded. It is quite clear, therefore, that injuries of the blood-vessels ending in the formation of traumatic aneurysms are not only very frequent, but probably more frequent in the present war than in all previous wars.

It is quite certain that in any future military experience the prophylactic value of débridement as a preventive of traumatic aneurysms will be firmly and unquestionably established.

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Anatomic Distribution.—With the exception of the several sectors of the war front in which trench warfare prevailed, the reports of all observers are practically unanimous in stating that the vessels of the

lower extremities, especially the femoral tracts, are the most frequent seat of injuries. The number of wounds of the smaller vessels at the extreme periphery (forearm and legs) is probably greatest in the field hospitals and ambulances at the front, where the secondary vessels (tibials, radial and ulnar) are treated coincidentally with other injuries. At the base, Makins states this relative incidence to be greatest in the femoral tracts, and places them in the following numerical order: Femoral, 35.2 per cent.; popliteal, 17.6 per cent.; carotid, 17.5 per cent.; axillary, 12.2 per cent.; brachial, 9.5 per cent.; subclavian, 6 per cent.; the other vessels in decimals of 1 per cent. Salomon states that in Rehn's clinic at Stuttgart 642 vascular injuries were distributed as follows: Head, 35; neck, 68; upper extremities from the subclavian to the hand, 242; lower extremities from the abdominal aorta to the dorsalis pedis, 297. This is very close to the relative proportion observed in the Russo-Japanese War of 1904–05.

Independently of the mode of warfare, the factors which determine the more frequent localization of gunshot injuries in the vascular tracts are their exposed position, their length and their caliber, which make them better targets for missiles. There are several anatomic conditions in certain regions which give them some chance of escape from the projectile by lateral displacement. As pointed out by Makins, vessels lying in a loose connective-tissue bed have a better chance of escape than those which are firmly anchored or closely adherent to fixed beds. When an artery gives off branches which encircle the underlying bone, as the femoral at Scarpa's triangle, the superficial femoral in Hunter's canal, the popliteal at the adductor foramen, and the tibial vessel in the popliteal space; the posterior tibial trunk, as it lies under the arch of the soleus, and the axillary as it is held to the neck of the humerus by the embrace of its circumflex branches, are all examples of anatomic fixation and immobility which predispose these vessels to gunshot injury.

The Relative Frequency of Vascular Injuries According to the Nature of the Projectile.—One of the notable peculiarities of this war is the greatly increased number of wounds caused by explosive missiles and fragments of shells, bombs, grenades, etc., which, in addition to the machine guns, have greatly added to the destructiveness of artillery fire. It was estimated by a military critic, writing on February 2, 1916, that in an advance by a French Army Corps the casualties had been accounted for in the following way: by shell and shrapnel, 70 per cent.; by the blowing up of mines, 5 per cent.; by small arms, 14 per cent.; by bayonet, 0.5 per cent.; by hand grenades, 3.5 per cent.; unknown, 7 per cent. In comparison, we find that in the Russo-Japanese conflict the casualties caused by small arms bullets on the Japanese side was 83.5 per cent.; by artillery projectiles, 13.5 per cent. On the Russian side the small rifle bullets caused 84.5 per cent. of the wounds; artillery and explosive projectiles, 14.5 per cent. (Lagarde).

On the other hand, while this great preponderance of artillery and explosive projectiles in the causation of war wounds cannot be doubted, it is nevertheless true that the greater number of *vascular* injuries are

PROPERTY OF SURGICAL OFFICE NOT TO BE REMOVED

caused by the small pointed rifle bullet. The only evidence that we have been able to obtain on this point is that furnished by R. Salomon (Beitr. klin. Chir., v, 112), who makes a comparative statement of the relative frequency of vascular injuries according to the wounding missile; *the pointed rifle bullet* was responsible for 81 per cent. of the traumatic aneurysms observed in the Frankfort hospital, of which 82.5 per cent. were through-and-through perforations and 17.5 per cent. with retained missiles. From the German literature of the war he finds that 74 per cent. of traumatic aneurysms were caused by rifle bullets and in 14 per cent. of these the missile was retained. Shrapnel caused, in his own series, 5.5 per cent. of the aneurysms, in 29 per cent. of which the missile was retained.

From all of the various statistics we gather that the largest number of aneurysms are caused by the small rifle bullet, but that the projectile is retained in the tissues in 57 per cent. of the shell or grenade injuries.

ANATOMIC LESIONS: CONTUSIONS

Contusions, in which a passing missile grazes or comes in contact with the walls of a blood-vessel without perforating it, have been fully considered in Volume V, p. 105. The frequency of this injury and its significance in the causation of thrombosis, secondary hemorrhage, and traumatic aneurysm, though well known, had never been fully realized until the present war. Several facts stand out prominently as the result of this experience, viz.: (1) That the extent of the damage done to a contused vessel cannot always be estimated by its external appearance, and that the structural alterations involving the intima and media extend far beyond the area of actual contact. (2) The inevitable sequel to a contusion of a blood-vessel is a quick thrombosis, which may be partial (parietal) or total (circumferential); localized, stationary, or progressive. If progressive, it may extend the full length of the vessel and spread up and down from the primary seat of the lesion. The tendency is toward complete obliteration of the lumen with secondary ischemia of the limb, and gangrene of the peripheral parts, especially if the thrombus involves a large section of the artery. (3) Thrombosis from contusion is a primary phenomenon dependent upon the mechanical damage done to the intima and media irrespective of infection, which, if present, always adds to its gravity and progressiveness. (4) The presence of the thrombus, even a minute parietal clot, is always fraught with the risk of secondary embolism. (5) Therefore a contused vessel may be silent or symptomless for some time after the injury, and the seriousness of the injury only becomes suspected or definitely recognized by the sudden appearance of ischemic phenomena in the peripheral parts (gangrene of toes or fingers), menoplegia, aphasia, and cerebral disturbances (in contusions of the carotid). Quite a number of amputations from this cause have been recorded during this war. (6) The more frequent sequel of contusion is the sudden rupture or gradual yielding of the weakened wall to the blood-pressure at the seat of the contusion, leading to secondary hemorrhage in open wounds, or,

more often, in narrow bullet tracts, to arterial or arteriovenous hematomas which, in turn, become traumatic aneurysms. Fully 2 per cent. of traumatic aneurysms are due to contusions (Salomon). (7) These effects, especially thrombotic, are felt with even greater certainty by the veins, and when both vessels are contused, aneurysmal varices will result. (8) Constitutional states (shock, anemia, perivascular extravasations) influence the formation of a thrombus by delaying or by accelerating the process. More often the intravascular clot is formed gradually and insidiously in the lesser contusions, thus giving time for the collateral circulation to compensate for the ischemic effect of the thrombus on the distal parts. (9) The diagnosis of vascular contusion cannot be established clinically until ischemic phenomena develop, viz., severe pain in the affected limb and vascular tract, pallor with evidence of *capillary stasis*, marbling of the skin, or cyanosis, loss of peripheral pulses, diminished control of the extremity, disorders of sensibility, etc., all following a recent gunshot injury in the vicinity of an important artery. (10) In such cases an exploration is usually undertaken under the impression that an arterial wound in the vessel exists, and the fact that a thrombotic occlusion is the cause of the disturbances will only be revealed by the exploration. (11) With the appearance of a thickened, hard, pulseless vessel, showing a discolored or damaged sheath, with possible punctiform necrotic spots, without perivascular hemorrhage, the diagnosis is unmistakable, and the only problem is how to deal satisfactorily with this condition.

(12) Treatment: The indications will vary with the state of the affected limb at the time of the intervention. When ischemic phenomena are marked, the peripheral parts pulseless, and signs of incipient necrosis of the digits are present, there is nothing to expect from the operation, and all that can be done is (when there is no infection) to wait for the line of demarcation. If the artery alone is involved, dry gangrene will occur; if the veins also participate in the process, moist gangrene; if the exploration is performed promptly with the first warning pains and the loss of the peripheral pulses, the proper course is to open the vessel, to extract the thrombus, and to determine the full extent of the damage done to the intima. The thrombosed segment should then be ligated above and below the thrombotic area and excised. The intima, however, should always be inspected to determine the extent of the damage. It would be ideal to close the artery by lateral arteriorrhaphy after the removal of the thrombus, but experience has shown that this procedure is a failure from the prompt reproduction of the clot. (See section on Thrombectomy and Thromboarterial Obstruction, Vol. V, p. 66.) (13) No amount of vaselin applied to the intima or irrigation of the injured vessel with sodium citrate, or other anticoagulant solutions will avail to prevent recurrent clotting if the intima has been damaged and thereby lost its protective influence against formation of a thrombus. (14) In cases of thrombosis in which the clot has formed gradually, thus giving time for the collateral circulation to compensate for the obstruction of the main channel, the

clot (if not infected) will organize into a cicatricial plug and the lesion will pass undetected, through lack of symptoms, as even the peripheral pulse may be quickly restored by the collaterals.

WOUNDS OF THE BLOOD-VESSELS

Gunshot wounds of the blood-vessels are classified in a general way into: (1) *Lateral* (transverse, longitudinal, or oblique); (2) *perforating*, which traverse the lumen of the vessel; and (3) *complete transverse section*. The character of these wounds and their anatomic peculiarities are extremely varied according to the projectile that inflicts them, whether this be a pointed rifle projectile of reduced caliber, a round shrapnel ball, or a shell fragment. The range of the missile and its velocity at the time of impact, in addition to its size and shape, determine the greatest variations in the character of these wounds. All of the wounds have a common feature, namely, that they are all more or less of a *contused* or *lacerated* type. It is also to be expected that in over 50 per cent. of these injuries the artery and satellite vein or veins are simultaneously involved; this is especially true of the vessels of smaller caliber in which the artery is accompanied by two satellite veins connected by transverse anastomoses, as in the tibial vessels.

Lateral Wounds.—These may be simple punctures caused by minute fragments of metal, such as may be derived from a portion of the mantle of a fragmented bullet or small particles of shell casings, etc. The fragments may enter the lumen, be arrested in the opposite wall of the blood-vessel, or may be carried away by the blood-stream. The migration of bullets into and from the heart through penetrating wounds in the periphery to the heart and vice versa, from the heart to the periphery, is one of the most interesting features of the present war. (See Bullets and Other Foreign Bodies in the Arteries Acting as Emboli, Vol. V, p. 76, and in the section on the Heart and the Migration of Bullets, etc., in this chapter.)

On the other hand, the gaps produced by some of the lateral vessels involving one-third to three-quarters or more of the circumference are followed by greater hemorrhage than those of complete transverse section; the partial sections, as well-known, interfere with spontaneous hemostasis by retraction, and, in addition, by a rotation of the partially divided segments of the artery upon its axis, thus directing the blood-stream away from its usual channel, pour the blood into the perivascular tissues, form pools, and create larger and more diffuse hematomata. This accounts for the not infrequent cases of traumatic aneurysms in which the peripheral end of the vessel is lost in the walls of the hematoma by obliteration and fusion with the surrounding tissues; the proximal end opening directly and singly into the cavity. This is especially noted in certain arteriovenous aneurysms in which a single arterial orifice is alone recognizable with one or two openings corresponding to those of the injured vein. In other cases a rifle bullet will punch out a clean-cut section of the vessel wall, leaving an oval or elliptic opening which involves only a comparatively small section of the

circumference. These are the lateral wounds that are most favorable for repair by suture. They represent about 50 per cent. of bullet injuries. At other times a sharp shell fragment may cause a simple incised wound, as if cut with a knife, either in the transverse, oblique, or longitudinal axis of the vessel, with or without impaction of the fragments, thus constituting parietal injuries without loss of substance which are still more favorable to repair. In any event, the degree or extent of the damage done to the intima and middle coat cannot be estimated by the external appearance of the wound in the adventitia, and this is particularly true of the effects of the pointed rifle bullet, which, on account of its instability of flight and axial rotation, usually adds an extensive area of contusion around any opening it may make.

Perforations.—A notable diminution in the frequency of through-and-through perforations has been noticed since the adoption of the *pointed* projectile, as distinguished from the older ogival or cylindro-conoidal missiles. The pointed projectile shows a tendency to turn on its short axis, at the slightest resistance; it is more likely to strike the vessel and the tissues by one of its longitudinal surfaces, full length, or even by its base, and this accounts for the torn and lacerated wounds and explosive effect which imitates so closely the destructive action of larger projectiles. This diminution, however, has been made up by the increase in the number of perforations caused by small fragments of bomb and shell propelled by high explosives (Makins). The fact that when the blood-vessels are perforated through and through by a bullet the size of the perforations, as well as the diameter of the vessel, are considerably smaller than the caliber of the missile, is proof of the great elasticity of the vessels, especially of the arteries, which flatten and expand laterally by the centrifugal displacement of the blood column as the vessel is hit by the projectile. That their immediate retraction, caused by the elasticity and contractibility of the arteries narrows the perforation to a minimum is well known.

Complete Division of the Blood-vessels.—The vessel may be cut clean across by a bullet, as if cut with a knife, or it may be torn apart, causing its divided ends to retract, curl up, and separate by a more or less long space. In striking contrast to this last injury are the contused and lacerated wounds caused by rough fragments of shells, or by the pointed rifle bullet at short range. In these the free ends of the vessels may be irregularly torn and lacerated with considerable lengths of the artery missing and actually carried away by the passing missile (Makins).

SPONTANEOUS HEALING AND OCCLUSION OF INJURED ARTERIES

The frequency with which injuries of the vessels have been found *spontaneously healed* is to be noticed as one of the results of the vast extension given to neural surgery during the present war. The spontaneous healing of large arterial trunks partially or completely divided has come to light by the discovery of the vascular lesion in the course of operations upon nerves. This observation is common to nearly all re-

ports dealing with large numbers of neural operations. The best known of these is probably Verebely's statement that he found this spontaneous healing in 35 instances among 636 operations for nerve lesions. This fact has been noted in connection with the axillary artery more than with any other vessel. Makins remarks that the great majority of these instances are due to contusions. The more interesting problem is found in the case of wounds of a more purely incised character. Of such, few examples are given, although postmortem examinations have afforded evidence that even the thoracic or abdominal aortæ have been perforated, and yet neither has a pulsating hematoma developed, nor has the accident led directly to the death of the patient. From such evidence as exists it may be assumed that spontaneous healing of arterial wounds is more frequent than has been generally believed, especially those inflicted by small fragments of bombs and shells. The disappearance of arterial or arteriovenous bruits in vessels of the magnitude of the external iliac or the femoral arteries, which undoubtedly indicated the presence of a wound, has been repeatedly observed also in many other vessels. It may be added that vessels which lie embedded in abundant loose connective tissue, such as the mediastinal or retroperitoneal spaces, are those in which spontaneous closure of the wound most readily occurs without the development of a pulsating hematoma, the blood clotting rapidly in the meshes of the tissue. Again, vessels in apposition with large nerve trunks taking a parallel course frequently heal in this manner as a result of adhesion of the nerve (Makins).

In reviewing the lesions of the blood-vessels in the present war solely from the anatomic and histopathologic viewpoint, it would not appear that any very notable additions have been made to our previous knowledge of these lesions as such, except to confirm on a vast clinical scale what was known before. It would also appear "that no useful distinction can be made between wounds of the vessels caused by bullets or fragments of shells, as far as the indications of treatment are concerned. Each injury, in fact, is to be judged on the actual conditions discovered on direct examination, and not upon the nature of the agent producing it, *always bearing in mind the greater probabilities of serious infection* of the neighboring soft tissues in lesions produced by fragments of shells" (Makins).

The chief conclusion that can be gathered from the anatomic study of gunshot wounds of the blood-vessels is that they show no uniformity of type, no matter what the projectile that has inflicted them may be. The fundamental divisions into lateral, perforating, and complete transverse wounds are mere pegs upon which to hang innumerable *atypical* variations which can never be anticipated, and are only recognized and identified when exposed to view in the course of a surgical exploration.

The **multiplicity of vascular wounds** caused by one projectile in the same individual is another peculiarity of war wounds. The simultaneous injury of the artery, with its satellite veins, is the most frequent instance, but several vessels occupying the same plane may be simul-

taneously injured, *e. g.*, the subclavian or the carotid and the vertebral, the common femoral, with the profunda and their veins, etc. At other times the same vessel or its branches may be injured at several points along its tract, this being peculiar to shell and other explosive injuries, as is often seen in hunting accidents with bird shot in which a number of small shot may strike the same part of the body.

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CLINICAL CLASSIFICATION OF GUNSHOT WOUNDS OF THE BLOOD-VESSELS

As distinguished from the purely anatomic peculiarities of gunshot wounds as observed in this war, the clinical grouping of vascular lesions offers much more striking and novel features. We may distinguish the following clinical types which we have adopted, with some modifications, from Mondor:

(1) Wounds with external hemorrhage; (2) wounds with internal hemorrhage and surgical anemia; (3) wounds with diffuse hemorrhage into the tissues and progressive hematoma; (4) wounds with circumscribed and pulsating hematoma; (5) wounds without hemorrhage, without hematoma, but with a suppression of the peripheral pulses; (6) wounds without hemorrhage, without hematoma, and without modifications or alterations of the peripheral pulses, but with large ecchymoses (Mondor type); (7) dry wounds with unaltered pulses without ecchymoses, but with local pain over the vascular tracts and a surprising functional disability (Sencert type); (8) dry wounds without a single symptom suggestive of a vascular lesion; (9) a number of rare cases in which all the signs of a vascular lesion exist—ischemic phenomena in the peripheral parts, pain, absence of peripheral pulses, but with bruits, even thrills and murmurs simulating arteriovenous lesions, all the symptoms in fact, except tumor—but in which surgical exploration has *failed to reveal any structural lesion or contusion.* These are the cases which for convenience we will designate as *pseudo-aneurysms* of angiospastic origin, and they constitute a strange and hitherto undescribed group which had never been brought to light until this war.

Wounds with External Hemorrhage.—These are usually large external, open wounds associated with a greater or less destruction of the soft parts, caused by the impact or passage of fragments of shells, bombs, or shrapnel, or by perforation caused by the pointed projectile, fired at close range, which has produced explosive effects, or led to the tearing or grinding of the tissues, sometimes causing the evulsion of a limb or a part of it.

If in such a wound a large vessel is clean cut, whether partially or completely, a profuse or overwhelming hemorrhage will follow which will quickly seal the fate of the patient. This is usually the most frequent cause of death on the battlefield. The fatality of these wounds is indicated by the comparative rarity of the wounds of the great vessels of the neck and root of the limbs among the survivors who reach the first-aid stations in field hospitals. On the other hand, it is a remarkable feature of this war that so many suffering with seemingly fatal wounds of the great vessels have escaped with comparatively little or no primary hemorrhage ("plaies seches," dry wounds of French writers). This is usually accounted for by the lacerated and contused character of the wound inflicted by artillery projectiles, or the pointed "Spitz" at close range. In these cases the sudden drop in the blood-pressure caused by shock and blood loss, combined with the retraction and curling in of the media and intima, have sufficed to block the torn and bruised vessels, thus securing a provisional hemostasis. At other times a clean-cut wound of an artery may bleed profusely, but syncope from exsanguination and shock will favor the formation of a provisional clot which, however, will be easily washed away with a return of consciousness and an increased blood-pressure. These are the *delayed* or *recurrent* hemorrhages that are observed in transportation, or at the first-aid and field stations.

The *"delayed"* hemorrhages are those in which primary hemorrhage has been prevented by spontaneous hemostasis in consequence of the local and constitutional conditions above referred to. In these cases the hemorrhage which was absent in the beginning will occur later when the vitality of the patient reasserts itself, and the

systolic wave, strengthened by returning consciousness, will break down the temporary hemostatic defences. The hemorrhage has been merely delayed, and will surely come unless the injured blood-vessel is promptly secured. Later, days and perhaps weeks after, if infection sets in, a new danger faces the patient. The natural spontaneous hemostatic processes which have successfully resisted the pressure of the blood-stream, and when repair has fairly begun will now crumble and give way in the presence of bacterial invasion; the hemostatic thrombus will soften and turn into pus, the walls of the blood-vessels will ulcerate and slough off, and the still more formidable *secondary* hemorrhage will follow.

As to the immediate management of *recent hemorrhages* from large vascular trunks, the experience of the present war coincides with that of all modern wars. In these the small, hard-jacketed bullet and explosive artillery projectiles have played the leading part, and from this point of view what was long ago observed from the South African War to the Balkan Wars, are in no ways essentially different from what has been observed in the present war. The early conclusions arrived at by Longmore, the British surgeon of the Crimean War, of Legouest, on the French side, as well as Pirogoff on the Russian, that primary hemorrhage from gunshot wounds of the large blood-vessels does not often come within the observation of army surgeons, is still borne out by the latest experience. When all the data on this subject become available we may modify this opinion. With the close proximity of surgical ambulances and stationary hospitals to the firing line, which had never occurred to the same extent in any previous war, it is quite probable that the relative proportion of primary hemorrhages brought to the first-aid stations has been greater than in previous wars. That the number of primary hemorrhages that reach the surgeon for treatment is not over one-half of the total number of the wounded suffering from injuries to the great blood-vessels, appears to be fairly well determined by the available material of the present war. For instance, according to Rehn, speaking at the Brussels Conference of the German Army Surgeons in February, 1918, reported that of 421 arterial hemorrhages, only 201 required ligation. Of these ligations, those of the brachial and femoral arteries greatly preponderated, whereas the common carotid lesions proved fatal on the battlefield, through exsanguination or asphyxiation, which accounts for the relative scarcity of operations on the common carotid for secondary hemorrhage or aneurysms. Also, of the subclavian vessels it may be said that the greater number proved fatal through primary hemorrhage, but as this is a very exposed part of the body, and wounds of this vessel are very common, a fairly considerable number of the more favorable cases reach the military hospitals on the rear lines of communication, where they are attacked by secondary hemorrhage or develop traumatic aneurysms.

The fact that in more than one-half of the cases simple measures suffice for hemostasis in arterial hemorrhages is borne out by the statements of the survivors, who subsequently developed traumatic aneurysms. This confirms the opinion that the greatest fatalities occur in the large open wounds with free external hemorrhage, and that the best chances for survival are given to those who bleed into their own tissues, owing to the narrow, small orifice of the external wound, which effectively prevents the large and rapid escape of blood. These are the cases of diffuse or circumscribed hematomata which claim separate consideration.

In fact, even when we come to the immediate treatment of these large bleeding or exposed blood-vessels we are still going back to the Napoleonic campaigns and applying the "golden rules" laid down by Guthrie, Dupuytren, Larrey, and Bell: "*Ligate at the bleeding spot*," "*Ligate while bleeding*," "*Ligate both ends of the bleeding artery, or above and below the wound in the vessel*," etc. (*vide* Vol. V, p. 119).

In the beginning of the war the same prelisterian experiences that characterized the oldest wars were repeated.

It was only after the first Battle of the Marne, when the battle fronts became fixed and stationary by trench warfare, that surgery first saw the dawn of a new day. Field ambulances, temporary first-aid shelters, C. C. S. in close proximity to the firing line now became stationary, and were equipped as efficiently as base hospitals. It was then only that the contrast between the new and the old surgery of blood-vessels and, for that matter, of all traumatisms in the Great War, became clearly apparent. We have already sufficiently referred to the practice of débride-

ment. The proximity of the first-aid stations and the facilities for quick transportation of the wounded from the firing line, so that the injuries could be dealt with in all their aspects, including the bleeding or wounded vessels, torn nerves, exposed joints, and shattered bones, as well as the greater splanchnic complications of the head, chest, and abdomen, made it possible to deal with these successfully within the first six to eighteen hours of the injury. In this way the general adoption of the principles of primary surgical and mechanical wound sterilization, first put into practice by Gaudier and Gray, became possible, and established a precedent which will prove one of the most fruitful lessons of the war in its relation to civil as well as military practice.

Unfortunately, these ideal conditions of prompt and efficient asepsis by prophylactic surgical wound treatment cannot be realized under all circumstances, and during active military operations combined with the necessity of shifting the location of the operating center, and the rapid evacuation of the wounded, there will always occur times when conditions unfavorable to the performance of operations of any sort will obtain.

For this and other reasons the unfavorable conditions of past wars will continue to a greater or less degree, and the great emergencies caused by vascular injuries will have to be met with the same methods and makeshifts of the past. The tourniquet—undesirable and dangerous as this is known to be in untrained hands—will always retain its place in controlling hemorrhage, especially in the extremities. In the more dangerous and inaccessible wounds of the great blood-vessels in the shoulder, neck, and head it is not applicable. Here temporary and systematic packing of the wound with sterile tampons or gauze saturated with antiseptic and styptic material (such as dry benzoinated iodoform gauze or physiologic coagulants) will still serve as life-saving measures. In wounds of certain regions—supraclavicular, neck, and the groin and armpit—where the tampon will often fail, the hermetic closure of the external or cutaneous wound by continued suture alone, or over a tight pack, will convert an open hemorrhage into a hematoma, and in this way will check the flood of blood until the general condition of the patient has improved, and time is given for a more direct and effective control of the bleeding vessel. The hemostatic forceps is indicated whenever this is visible or can be made accessible. It should never be thrust blindly into a bleeding cavity or into a wound track where there is a probability of damaging important nerves or organs by clamping the vessel and the surrounding tissue *en masse*.

It is also in dealing with the great vascular emergencies in improvised and not wholly equipped centers of surgical relief that resort to the ligature will impose itself as a prime and unavoidable necessity. On this subject there is still some difference of opinion and practice which has been most apparent in this war. While the surgeons of the Allied Armies are practically unanimous on the preference that is to be given to the ligature, there are still some surgeons on the German side who believe in the superiority of the suture as a primary hemostatic and conservative measure. The judgment of the surgeons of the Allied Armies on this subject are unequivocally stated in the Syllabus of General Principles Guiding the Surgeon in the Treatment of Wounds in War (*Communications Techniques du Service de Sante Militaire*, Serie II, Chirurgie). This was issued as an official document by the French Government. In these conclusions it is stated that: "Vascular wounds with external hemorrhage require treatment beginning at the First Aid Stations and ending at the Ambulance (Field Hospital or Casualty Station)." At the First Aid Station the management will vary according to the amount of hemorrhage. If the hemorrhage is moderate, compression should be applied above the wound, or in the wound itself, by the tampon or pack. If the hemorrhage is very profuse and persistent, a tourniquet should be applied; all the wounded bearing a tourniquet must be provided with a distinct tag, and be immediately evacuated to the surgical ambulances (Field Hospitals), where they must receive immediate attention upon arrival. British surgeons apply forcipressure and reject the "garrot" constrictor, Spanish windlass, or tourniquet. [Certainly this is not an absolute prohibition, because British surgeons did and do apply the tourniquet wherever this is deemed necessary and unavoidable. See Makins, *loc. cit.*, p. 33.] "At the surgical ambulances treatment will consist, as a general rule, in the exposure of the damaged vessel at the injured point and the ligation of divided segments, or on each side of the injury, in healthy tissue. Vascular suture, lateral or circular, is the ideal operation when conditions are favorable. (Limited and readily accessible vascular lesions in aseptic wounds which can be completely closed.)"

The German surgeons and their allies are almost universally in favor of the suture of wounded blood-vessels wherever the suture is at all practicable. Judging

by the very large number of sutures reported in the German medical press during the war, the practice of arteriorrhaphy has become almost universal among them, in this way contrasting very notably with the experience of the Allied surgeons, who, while recognizing the theoretic advantages of the suture, and recommending it as the ideal procedure, have seemingly found for it a very restricted field of application.

In the beginning of the war the Germans regarded all infection in a wound as an absolute contraindication to the suture. At present they do not hesitate to resort to it, even in the presence of suppuration or moderate infection. They therefore limit the application of the ligature to the great emergencies of the fighting line, to local conditions that make the suture mechanically impracticable, and when the wound is badly infected. Apart from these limitations, they regard the suture as the method of election, and claim that the results obtained by this procedure are far superior to those of the ligature, not only diminishing the actual number of peripheral gangrenes, but in preventing the secondary, degenerative, atrophic, and the neuroparalytic disabilities that result from the impaired circulation following the ligature. Based on these and other premises, to be considered later, some prominent German surgeons would banish the ligature from the field stations, and substitute the suture as a routine procedure at the front, but the large majority admit that in spite of their avowed partiality for the suture as the method of election, the ligature of vessels is unavoidable in field work, and in dealing with all bleeding vessels in great emergencies in which immediate hemostasis is imperative (Bier, von Haberer, *et al.*).

But in weighing the advantages claimed for the suture, it should be borne in mind that the majority of the numerous arteriorrhaphies and angiorrhaphies, reported in the German surgical press, have been performed chiefly for traumatic hematomata and secondary aneurysms in which aseptic conditions prevail, and in which the peripheral circulation has had time to develop through the collaterals. The circumscribed or encysted traumatic aneurysms have been especially favorable for this work, whereas the open hemorrhages, and primary diffuse and progressive hematomata, which allow of no delay, and have to be dealt with at the front, have been treated more often, if not wholly, by the ligature. It is in this latter group of cases that the prospects of either the ligature or the suture are most unfavorable. It is primarily in these that conservative measures, calculated to restore the continuity of the injured vessel, are most urgently indicated.

Since the introduction of the technic of prophylactic excision as a primary treatment of wounds, it is probable that the number of secondary gangrenes following the ligature has diminished, but the statistics that would permit of a comparative estimate of the effect of ligation before this method was adopted, and since its adoption, are not yet available. That the practice of excision has made a great difference in the incidence of gangrene following ligation for secondary hemorrhage can scarcely be doubted; but that it has reduced the number of gangrenes following the ligations for primary hemorrhage, in which shock, acute surgical anemia, and exposure play a great part, is questionable. At any rate, the total number of gangrenes following or associated with surgical lesions of the great vessels at the front is excessive.

In this connection Sencert has made a valuable observation which, if confirmed by a further investigation, would modify our ideas in regard to the gravity of the ligature as a cause of gangrene when applied to *primary* wounds of the blood-vessels in the course of a prophylactic surgical wound sterilization. He endeavors to prove that the ligation of the main artery in open gunshot wounds under these circumstances is not followed by gangrene of the limb from ischemia, as we had been led to believe before the war, and before the mechanical cleansing and surgical sterilization of the wounds had been adopted as a routine practice by the Allies. He admits that gangrene *does* often follow the ligature when this is applied to large, diffuse extravasations and hematomata in which the lacerated tissues and pressure effects of the clotted blood and great perivascular tension, block the collaterals and leave the distal parts deprived of blood too long to benefit by the release of tension, after the hematoma has been evacuated and the artery ligated. He contends also, and very truly, that the mere ligature of a large arterial trunk does not suffice to produce gangrene. It is the condition of the vessel and the surroundings in which this ligature is applied that count, and these conditions have not been sufficiently analyzed by statisticians, and that it is this misinterpretation of the gross facts that had led to the bad reputation of the ligature in military surgery. "The true causes of gangrene, when it occurs after ligature, are those which interfere with the establishment of the collateral circulation. It is vascular thrombosis extending from the ligated segment to the openings of the collaterals underlying it; it is the peri-arterial hema-

toma, which extending above and below the wound, compresses and obstructs the collateral tracts." Now, in the large open wounds that we are considering, there is no interstitial extravasation, no compressing hematoma, but the vessel and its branches are exposed in an open space, or one practically free from pressure. If the wound as a whole, and the wounded artery in particular, is subjected to the thorough surgical and mechanical toilet by which all sources of contamination and tissue necrosis are removed, the dangers of thrombosis which are the consequence of vascular contusion, prolonged ischemia, and infection need not be feared.

This is not always the case when the artery is ligated for diffuse arterial hematoma. Under these circumstances the main artery and the collaterals have been obliterated by the increasing tension of the extravasated blood, and have been definitely paralyzed and made unfit to regulate the peripheral blood-supply even after the clot has been evacuated. [I would add that apart from the direct injury done to the blood-vessel, the degenerative changes that occur in the intima of the arterioles and capillaries by the effect of prolonged anemia predispose to cellular necrosis, even when the impaired collateral circulation is tardily restored.] Sencert has kept notes on 70 cases in which he ligated the great vascular trunks in open wounds within the *first few hours* following the injury, and in which there was no hematoma. In all these 70 ligations, which involved the carotids (common carotid), axillary (10), external iliac (1), femoral (11), popliteal (6), and other less important branches, there were only two gangrenes. One of these was a ligation of the femoral, the other of the popliteal. On the other hand, he ligated 42 large arteries for diffuse hematoma, and counting only the ligatures which were applied to the large, dangerous arteries, he had gangrene in 6 cases: 2 gangrenes in five axillary ligations; 2 in ten femoral ligations; and 2 in five popliteal (or 30 per cent. gangrenes). Therefore Sencert concludes in a general way that in large open wounds which are subjected to thorough and systematic surgical cleansing, the ligature of the large arterial trunks when applied to healthy segments of the vessel is not only the simplest and safest procedure for the patient, but is also relatively safe for the limb.

Makins lays more stress upon the *constitutional conditions* that lead to peripheral gangrene in primary wounds of the blood-vessels, as these are seen and treated at the front, and on the lines of communication during transportation from the front to the base. He tabulates 86 ligations of the large vessels (axillary, brachial, femoral, popliteal) which were applied for hemorrhage at the front. These were followed by gangrene of the extremities in 8, or 10.5 per cent. The ligation of arteries of the same magnitude at the base hospitals (presumably for circumscribed arterial hematoma or traumatic aneurysms) was followed by gangrene in 7 per cent. He also shows that the ligatures performed as a necessity for recurrent or secondary hemorrhage along the lines of communication are still graver than the ligations at the front. Thus the femoral, at the front, yielded 14.8 per cent. gangrene, at the base, 5.5 per cent., and 20.4 per cent. on the lines of communication. The popliteal ligatures were followed at the front by gangrene in 15.3 per cent., at the base, 16.6 per cent., and on the lines of communication, 39.5 per cent.

These statistics are not very different from those compiled before the war and from the literature by E. Wolff, of Jena, in 1908. They also contrast the difference in the effects of a ligature applied for the arrest of hemorrhage, in which the local and constitutional conditions are unfavorable for the development of the collaterals, and the effect of ligatures for the cure of aneurysm in which the collateral circulation is fully established. Thus, in ligations of the large arteries of the *lower* extremity for aneurysm, gangrene occurred in 14 per cent.; the same vessels ligated for hemorrhage resulted in gangrene in 37.5 per cent. In the ligations of the arteries of the *upper* extremities for aneurysm, gangrene in 5.6 per cent.; in the ligations for hemorrhage the gangrenes amounted to 13 per cent. In these statistics there is no attempt made to differentiate between ligatures in open wounds or in diffuse hematomas. They only confirm the established fact that the associated general and local conditions of war trauma, which usually accompany all important vascular injuries, and interfere with the efficiency of the collateral as well as the general circulation, are infinitely graver at the front than at the base.

Makins emphasizes the evil influence of these general conditions in this statement: "The occurrence of massive gangrene of the limbs, or the development of signs of anemia of the brain in young, healthy men can hardly be considered to depend upon any other cause than the existence of a low blood-pressure and an insufficient total amount of blood, and the safest way of avoiding accidents with such patients is to defer surgical intervention, whenever possible, until the general condition of the patient is improved. The existence of infection also bears a twofold

importance in this respect: on the one hand, the subjects of general infection are especially susceptible to gangrene of the simple anemic type; on the other, a local diminution of the amount of blood supplied to the limbs is an all-important factor in favoring the development of anaërobic infections."

No one can doubt the correctness of these observations, and no one can question the wisdom of delaying any operation under the circumstances above suggested. It is, precisely, because of the great danger of infection that the practice of primary prophylactic excision of war wounds has been so universally adopted by the Allied Armies. If this is to remain as the established rule of practice in the future, it is quite clear that the opportunity for delaying the intervention on the arteries cannot obtain. Delay is fully justified in dealing with injured blood-vessels when the wound is virtually aseptic and the hemorrhage is internal, or interstitial, limited and localized, as in the circumscribed hematomata. But long delay is not possible in contaminated wounds, whether open or closed, and the wound must be exposed, if the patient is at all able to stand any operation. Here, then, the wounded vessel must be dealt with on the spot. It is plain that if the peripheral nutrition is already menaced by an inadequate circulation the suppression of the main channel will only aggravate the existing ischemia. When an artery is completely divided, the effect of the injury is like that of a ligation, and if the limb or distal parts show signs of vitality, the ligation of the two ends in the wound cannot add to the troubles of the circulation. But, if the limb is cold, pale, pulseless, and evidently bloodless, then every effort must be made to restore the continuity of the blood-stream to the periphery. When the continuity of the blood-vessel is only partially interrupted, as in lateral or perforating wounds, and the limb is still fairly nourished by the main or collateral channels, it then becomes a matter of great importance to determine what the effect of the total occlusion of the vessel by ligation will be. Under these circumstances, if the wounded soldier has recovered sufficiently to permit of a débridement so thorough that broken bones can be properly set by open methods, joints cleansed and closed, nerves sutured, devitalized muscles and other tissues excised, and foreign bodies removed—there is no reason why the blood-vessels should be merely tied as a routine and the dependent parts trusted to the collaterals and to fate. The number of gangrenes following ligation at the front is, as we have already insisted upon, excessive, and everyone recognizes that the number of amputations that are performed for gangrene is deplorable.

Everyone is agreed that everything should be done to minimize the conditions that bring about this mutilation, or to avoid cerebral disasters when the carotids are occluded. All the surgeons of the belligerent armies have agreed that whenever circumstances would permit the continuity of the large wounded blood-vessels should be restored. If this restoration is indicated and urgent at any time, it is in dealing with the wounds of the large blood-vessels on the firing line. It is at this time that any disturbance in the balance of the peripheral nutrition which will still further cut off the scant supply of blood that is barely sufficient to sustain the life of the peripheral tissues will seal their fate. This restoration of the continuity is not so vital or necessary at a later stage when the resources of the general and collateral circulation have had time to display themselves (and yet it is here that the methods of suture have in all probability been applied with unnecessary frequency, especially in German practice during the war). The greatly reduced number of ligations of the main arteries for traumatic hematomata and aneurysms proves this. It is at the front that conservation of the main or parent arteries, in their functional value, is imperatively called for. With every allowance for the varying conditions of warfare, and granting that in many cases, and practically in the majority, the conditions under which the surgeon is placed will barely permit him to apply the most elementary procedures essential for life saving, there is no excuse for the neglect of the vital indications furnished by wounds of the great blood-vessels when the opportunity is given for the toilet of war wounds, as previously described, or the patient has sufficient vitality to undergo a laparotomy for a gunshot wound of the abdomen, a craniotomy for an injury of the brain, a thoracotomy for a foreign body, an arthrotomy for a joint injury, etc.

That the Allied surgeons recognize the need of a greater discrimination in the treatment of large vascular wounds is shown by the greater favor with which the methods of suture have been regarded and accepted during the last two years of the war. Thus Sencert, while holding the ligature as the method of election, recognizes and recommends that in performing a primary toilet of the wound a lateral slit or perforation should be sutured whenever this can be done without obliterating the lumen. Unfortunately, this only solves a small part of the problem, and does not satisfy the requirements of a complete section of the artery. This is done, however,

by intubation with an artificial conduit, a procedure which was introduced by Tuffier in 1915 as a substitute for end-to-end anastomosis or circular arteriorrhaphy. The ease with which a paraffined silver tube which is adjusted to the caliber of the injured vessel, and is capable of maintaining its patency for a sufficient period to allow the collateral circulation to be established, overcomes, in some measure, the more serious objections that have been raised to the performance of circular sutures in the field hospitals. Its readiness and simplicity account for the great favor with which the Tuffier tube has been received, especially by British surgeons.

The advocacy of Makins and other British surgeons of the simultaneous ligation of the satellite vein with the injured artery, in accordance with the older view of Ceci and von Oppel, as a means of increasing the low blood-pressure in the peripheral circulation, and thereby tiding over the nutrition of the distal parts until the collateral circulation can be established, shows, if nothing else, that there is a growing appreciation of the urgent need of greater discrimination in the methods of primary treatment of wounded blood-vessels at the front than has been accorded to these in the past.

Again, the steady rise in favor among French surgeons of the Pachon oscillometer as a means of testing the efficiency of the collateral circulation, as a preliminary to the occlusion of the great arteries, and in guiding the line of surgical conduct, is also a sign of progress in a much neglected field of surgical opportunity and usefulness.

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The Tuffier Tube.—The tube devised by Prof. Tuffier in 1915 is a very thin silver tube, 5 cm. in length, slightly bulbous at each end, with a highly polished interior, and a caliber to fit the normal diameter of the common carotid and femoral arteries. I would suggest that this diameter (according to the accurate scale of measurements of the arteries in relaxation, given by Ballance and Edmunds*) should be in the carotid tube about 8 mm. and in the femoral tube 10 mm. Great care should be observed in rounding off and curving the edges of the openings to prevent any injury to the intima in the process of introduction into the open mouths of the divided vessels. The vessels should be controlled with a soft elastic or padded forceps when intubation is performed on vessels like the carotid or common femoral in which perfect hemostasis cannot be obtained by the elastic constrictor and bandage.

I have had no personal experience in the application of this tube, but according to Tuffier and Makins it is most important that it should be thoroughly coated with paraffin and that the paraffin mixture in which they are immersed should not be disturbed in the process of introduction. "The free margins of the apertures are the parts most likely to suffer. Introduction of the tube into the proximal end of the divided vessel is easy, but that in the distal end often gives trouble from the fact that it is already contracted and difficult to dilate mechanically." To facilitate the introduction into the divided ends of the artery these should be well sprayed or directly lubricated with liquid vaselin after all the ragged edges are cut off and all adhering clot removed. The operation is much facilitated by a special forceps devised by Tuffier, which does not crush the tube while favoring its manipulation. After its introduction the tube is made fast to the artery by a ligature tied over the vessel at both ends. After the operation the blood should flow freely through the tube, as shown by the vigorous pulsation of the artery on the distal side.

The Bazett paraffin mixture used to coat the inner surface of the tube is prepared according to Makins as follows: Equal parts of paraffin wax and vaselin are mixed, the proportion of each being slightly modified, so as to obtain a mass which will set at from 43° to 48° C. The mixture is then strained through absorbent cotton between two layers of gauze, the tubes are coated by immersing them in the mixture heated to about 130° C., taking care to avoid the presence of air bubbles. We imagine that the excellent paraffin mixture introduced by Kimpton for the

* Ballance and Edmunds: The Ligation of the Arteries in Continuity, 1891.

coating of the Kimpton-Brown glass tubes used for blood transfusion would do admirably for this purpose.

After the coupling of the vessels has been completed the excess of vaselin can be washed out of the tissues with ether, and the wound closed with or without drainage, as the operator may deem necessary. The extremities should be kept warm and well protected in a heavy double folded quilt cover, which will keep the extremity immobilized without compression. Careful note should be taken of the status of the peripheral circulation. Tuffier uses the Pachon oscillometer to determine the daily variations in the peripheral blood-pressure, and if the nutrition of the parts appears to be well maintained, the wound is reopened at the end of seven or ten days, the tube is extracted, and the artery ligated at both ends.

The principle upon which the Tuffier procedure is based is that glass or metallic tubes, well coated with paraffin, will resist clotting or thrombosis for a sufficient time to allow the collateral circulation to assert itself. It was long ago demonstrated by Robert Abbe (in 1894) that even the abdominal aorta could be successfully intubated with a glass connecting tube after complete division, and could remain indefinitely in the vessel with apparently no ill effects, at least in the cat. Subsequently, Carrel and others confirmed Abbe's experience in the dog, under better conditions and with equally striking results. The use of the paraffin tube was also suggested by the paraffin tubes used in blood transfusion (glass, Brewer; platinum, Lespinasse). Thus far the method has been applied successfully by Tuffier, Makins, and many British surgeons. No statistics are yet available, but some of the published reports show that the tube may remain free from coagula for fully ten days or perhaps longer (Tuffier), while in others thrombosis occurs much earlier (four days). Careful observation of the peripheral circulation should be systematically kept up. The Pachon oscillometer will tell when plugging has occurred by a perceptible diminution in the range of the oscillations and in the fall of the blood-pressure. Thus far the results have been very satisfactory. Makins relates a striking case under the care of Captain Cowell, in which the signs of incipient gangrene had appeared after the ligation of a completely divided femoral artery. Cowell removed the ligature and introduced a Tuffier tube, with the result that gangrene was avoided. The serious objection to this procedure is that the wound is reopened and the tube removed. Makins says, as a rule, it should be removed in four days. The time for the removal of the tube should be determined, in my own opinion, by the readings of the peripheral blood-pressure, and the Pachon is an admirable instrument for this purpose. The reason for this haste in removing the tube is evidently due to the fear of a possible extension of the thrombus or the detachment of an embolus. It would appear to me that as long as the peripheral circulation shows no signs of serious disturbance and there is no infection, the tube should be allowed to remain undisturbed. Sterile metal, and especially silver, is particularly well tolerated by the tissues, and there is no reason why the tube should not remain in the blood-vessel indefinitely, even if completely blocked, as long as there are no signs of extension of the contained clot. What is important is that while the collateral circulation is being established the peripheral circulation should be kept up by frequent hot-air baths, gentle rubs, and massage, without, however, disturbing the limb, or allowing voluntary flexion movements for at least four to six weeks when the organization and limitation of the endotubal clot will be assured.

VASCULAR INJURIES WITH INTERNAL HEMORRHAGE INTO THE TISSUES; INTERSTITIAL HEMORRHAGE; HEMATOMA (ARTERIAL AND ARTERIOVENOUS); ARTERIOVENOUS ANEURYSM

In wounds caused by rifle bullets, machine guns, artillery projectiles, and fragments of shell which penetrate or perforate the tissues, leaving comparatively small, external cutaneous wounds, the wounds of the blood-vessels are followed by an extravasation of blood which is retained in the tissues and may give rise to *profuse*, *moderate*, *slight*, or *no* external hemorrhage. According to the nature and extent of the vascular injury and the resistance of the tissue planes, the extravasation may be immediate, rapidly progressive and widely diffused, causing voluminous tumors which are associated with marked surgical anemia. They also threaten the life of the limbs by compressing the

subcutaneous and perivascular tissues and obliterating the main trunk and its collaterals. These extravasations may be classified into: (1) The *diffuse and progressive arterial hematomata* which are the most frequent cause of peripheral gangrene in war wounds of the extremities, and require immediate or prompt action to relieve the perivascular tension and the occlusion of the vessels which threaten the life of the limb. When the tension is very great and the subcutaneous tissues have become hard and rigid from general hemorrhagic infiltration, there is no visible or recognizable pulsation of the tumor. If the extravasation has not advanced to actual strangulation of the limb, and the circulation is still maintained, there may be a large even impulse transmitted to the mass by the systolic wave, which is quite characteristic.

(2) When the extravasation occurs in the more restricted musculoaponeurotic planes and is confined to the neighborhood of the perivascular spaces, where greater obstacles are offered to the diffusion of the extravasated blood, then the hematoma may become *circumscribed*, forming a well-defined pulsating tumor of variable size, constituting the "circumscribed," "pulsating," "arterial" (Cruveilhier), "encysted," "communicating" (Wieting) hematomas of various authors.

The hematoma may terminate in one of several ways: (*a*) It may remain small and circumscribed for some time, hours or days; then suddenly, through the detachment of an obturating clot, or the giving way of the perivascular tissues through accident in transportation, restlessness of the patient, or rise in the blood-pressure—a profuse or secondary hemorrhage may occur which transforms the circumscribed into a diffuse hematoma; or the blood may find its way through the external wound, causing external hemorrhage. In these conditions immediate intervention becomes necessary; the extravasated blood must be evacuated and the vessels secured in the wound. (*b*) The hematoma may become infected and evolve into a diffuse or circumscribed phlegmon varying in virulence with the character of the invading organism. These infections almost invariably follow in hematomas caused by artillery projectiles which are almost always infected. In opening these the greatest precaution must be taken to control the circulation on account of the profuse hemorrhage which follows the relief of tension upon evacuating the pus and the magma of the sloughed and devitalized tissues. This is particularly important in the neck, axilla, and groin, in which prophylactic hemostasis by circular constriction is difficult or impossible. (*c*) The effused clot in a circumscribed aneurysm may harden and shrink in mass, and if this coincides with the obliteration of the wounded vessel by a thrombus, gangrene of the distal parts will follow. (*d*) Spontaneous recovery; the less frequent occurrence; when this happens the main trunk becomes obliterated at the seat of injury by the organization of the endovasal thrombus, with preservation of the collateral supply of the distal parts. In this event the hematoma is cut off from the circulating stream, and the extravasated blood and perivascular clot undergo retrogressive changes which favor the normal processes of absorption and elimination by phagocytosis without inter-

ference from the blood-stream. The injured tissues are then repaired and regenerated by granulation tissue and spontaneous recovery takes place, leaving the injured artery obliterated by a cicatricial plug with a total disappearance of the tumor. Again, and more rarely still, (*e*) the main artery may be temporarily compressed by the clot under tension sufficiently to obliterate its lumen. Under these circumstances all the signs of an active pulsating hematoma will stop, leaving the impression that spontaneous cure is about to take place. Later, with the absorption of the clot and relief of tension, the circulation in the artery will be restored and the signs of aneurysm will reappear—a *relapsing* hematoma. (*f*) The more common termination, especially in tangential and transverse perforating wounds, is that the hematoma will become progressively more limited and circumscribed, finally evolving into a typical *traumatic aneurysm.*

As long as the extravasation is confined to an irregular cavity with anfractuous walls formed entirely by displaced and torn perivascular tissues without a well-formed, limiting membrane or sac of new formation, it is a hematoma, which may be arterial or arteriovenous. *A hematoma only becomes a traumatic aneurysm* when the limiting cyst-like sac is formed. The mode of formation of these sacs and their histopathology has been sufficiently studied (Vol. V, Chap. VII) and need not detain us here except to point out that the experience of the present war has added no new knowledge in regard to their clinical characteristics or pathogenesis.

Pathogenic Concept of the Traumatic Aneurysmal Sac.—Therefore, merely to emphasize the present conception of the mode of formation of these traumatic or false aneurysmal sacs, we will lay stress upon three orders of phenomena: (1) The periarterial blood-clot and parietal hemostatic thrombus, under the constant pressure of the blood-current, reinforced by the intermittent systolic impact, gradually stretches and is hollowed out in a more or less spheric or ovoid form until it is molded to the shape of the cavity in which it is contained. The clot is hardened, molded, stretched, and stratified until it meets the resistance of the tissues, which are also constantly reinforced by inflammatory exudates to resist the pounding of the systolic impact. The clot acts as a buffer between the impact of the blood-stream and the injured tissues. Gradually the clot becomes organized by the infiltration of the fibroblasts and angioblasts, which transform it into a living membrane, the original clot being gradually removed by the leukocytes and larger phagocytic cells. With the maturity of the connective-tissue cells a new living tissue is formed which becomes the basal membrane of the future sac.

(2) Simultaneously with the organization of the clot the endothelium of the injured blood-vessel proliferates and spreads rapidly from the lumen at the edge of the perforation, and gradually lines the interior of the cavity, giving it that characteristic, polished, bluish or reddish-white lustrous appearance that is identical in appearance with the interior of the parent vessel. This endothelial "varnish" is most typical

and thickest at the neck of the sac where the interior of the artery blends with the new sac wall, and wherever the current of the circulation is most active. It is lost and practically undeveloped in the distant or dead pools of the sac, where the blood has coagulated into stratified layers and laminated clots which rest against the basal membrane of the sac. *It is a well-established law in vascular pathology that the endothelium disappears wherever it is not needed, and, conversely, it is present and most typical wherever the circulating stream is most active and is to be protected from the thrombogenic action of the tissue juices.* When the sac and its lining are thus formed, the hematoma becomes a traumatic aneurysm. As long as the sac is not formed as a clearly differentiated membrane the clot can be wiped away by mere sponging or irrigation; when an aneurysmal sac is formed it becomes adherent to the tissues and to the parent vessel. It can only be removed then by enucleation, dissection, or excision. *As long as its relations to the surrounding parts are not disturbed it is a living tissue which reacts in every way like the interior of a blood-vessel or of a serous sac, and only differs from a blood-vessel in its lack of elasticity and contractility. The fact that it is a living membrane which reacts to trauma as any endothelial structure or surface, by plastic exudation and endothelial proliferation, is a very important consideration in the surgical treatment of these traumatic aneurysms.*

(3) The walls of the perivascular space which form the background of the aneurysmal sac undergo marked changes in their structure. They react to the injury and the presence of the clot by the outpouring of plastic exudates, by the infiltration of leukocytes, which are soon followed by an invasion of the embryonal tissue cells which prepare the way to the formation of the limiting pseudomembrane.

The time required for the transformation of a circumscribed hematoma into an aneurysm as above defined is variable; but it is usually not less than six to eight weeks.* (Haberer has seen a well-defined sac formed in eight days.) Long before the sac is formed, however, the thickening and rounding off of the edges of the wound in the blood-vessel can be noticed. Endothelization begins early at the edges of the wound, where it merges with the surrounding connective tissue of the sheath. This incipient lining may be noticed at the end of the second or third week and is of decided advantage in favoring the closure of these openings by the endo-aneurysmal or intrasaccular method of suture as distinguished from the simple arteriorrhaphies and angiorrhaphies of the early posttraumatic period when the injured vessels lie naked and practically unchanged at the bottom of a rough blood-infiltrated, lacerated cavity.

(*g*) *Arteriovenous Aneurysms.*—As already stated, the coincident injury of the artery with its companion vein, or with its two satellites,

* Aneurysms are classified also into "*immature*" and "*mature*," according to the stage of development of the pseudosac, usually corresponding with the age of the lesion. The bearing of the age of the lesion on the mode of treatment is very considerable according to the technic adopted by different operators, and will be again referred to under Treatment.

is one of the most frequent and characteristic injuries of the blood-vessels in modern warfare. The coincident injury of the artery and vein occurs in 50 to 60 per cent. of all vascular injuries, and the proportion of the arteriovenous to the pure arterial traumatic aneurysms as observed at the base hospitals is fully 50 or 55 per cent. and even, sometimes, 70 per cent. (Hotz) of the total number. As already explained, the preponderance of artillery fire and explosive shells have only added to the steadily increasing number of these associated or bivascular injuries, as observed in the present war. The developments in civil and war surgery during the last ten years have only confirmed and emphasized the facts that had already been acquired by previous experience. After a careful survey of the literature of the last decade I find little to add that is of essential or fundamental importance in the discussion of arteriovenous aneurysms as presented in Vol. V, p. 290. The vast clinical material offered by the war, however, has yielded fruitful results in the recognition of the relative preponderance and incidence of these aneurysmal types and of the effect that these types, or, rather, their special architecture, may exercise in the selection of the operative treatment.

In an analysis of 272 traumatic aneurysms Makins found that 120 were arterial and 152 arteriovenous, and that of the latter, 52 or one-half plus, were aneurysmal varices. The bivascular lesions occurred with greater frequency in the carotid and femoral tracts, and in these also the aneurysmal varices predominated. The classical subdivision of arteriovenous aneurysms into *varicose aneurysm* and *aneurysmal varix*, or arteriovenous fistula ("phlebarterie" of Broca), according to whether the communication between the artery and vein is a direct anastomosis or takes place indirectly, through an *intermediary*, a *communicating*, or a *common* sac, remains as in the past. Recent experience, however, has considerably modified our older impressions in regard to the relative frequency of these modes of communication. The direct anastomosis or fistula is by far the preponderating type (56 per cent. and more, of all cases), and the so-called varicose type is subject to numerous variations. I have endeavored in a previous discussion of the subject (Volume V) to show in a diagrammatic way all the theoretic possibilities of these arteriovenous combinations. Makins now contributes a series of diagrams which show these combinations as they have been actually observed in the course of operation and, in this way, they are especially instructive.

The aneurysmal pseudosac in the mixed injury (the so-called varicose type) is to be regarded as purely arterial in nature, and is always directly connected with the wound in the artery. The vein plays but a secondary part, although as a result of the local dilatation which always takes place it furnishes a considerable proportion of the whole bulk of the tumor.

"The diagrams representing transverse sections through the aneurysm illustrate various ways in which the arterial sac may be arranged. A is a pure aneurysmal varix; in B the arterial sac is interposed between

the artery and vein; in such cases the missile has probably passed between the two vessels and caused a lateral wound in the opposite side of both. In D an arterial sac has been found in connection with the wound on both sides of the artery, and thus a sac springs from the far side of the vessel as well as from that opposed to the vein. This arrangement is the result of the passage of a missile which has traversed both vessels, the wound on the free aspect of the vein having closed spontaneously. In C the sac springs from the free sides of the artery, while a direct communication has been established between the artery and the vein. This arrangement also results from a traversing injury, and we have the condition of an arterial aneurysm and an arterial varix combined. In E and F the missile has crossed the vessels on the superficial or (more often in gunshot wounds) the deep aspect. In E a common opening of the two vessels communicates with the sac situated at the angle of union. In F the sac has a separate opening of each vessel" (Makins).

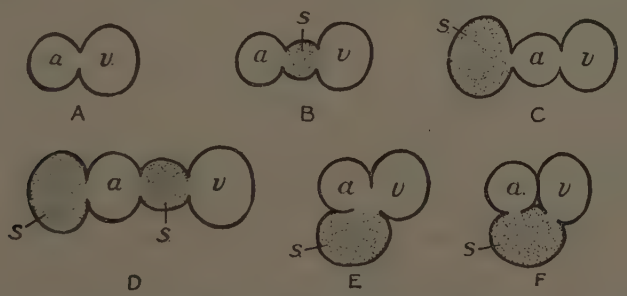

FIG. 327.—*A*, SIMPLE ANEURYSMAL VARIX. *B*, ARTERIOVENOUS ANEURYSM (CLASSICAL INTERPOSED SAC). *C*, ARTERIAL ANEURYSM COMBINED WITH ANEURYSMAL VARIX. *D*, ARTERIAL AND ARTERIOVENOUS SAC. *E*, ARTERIOVENOUS SAC WITH *Common* OPENING OF COMMUNICATION LEADING TO BOTH ARTERY AND VEIN. *F*, ARTERIOVENOUS SAC WITH SEPARATE OPENINGS OF COMMUNICATION WITH ARTERY AND VEIN. (FROM Makins' "On Gunshot Injuries to the Blood-vessels.")

Of these combinations, the aneurysmal varix, as has been repeatedly stated, is the most frequent, not only in all the war reports but also in civil practice. Of the so-called *varicose* type, the interposed sac is far less frequent than is classically taught, whereas in my own experience, confirmed by practically all the leading surgeons in the Great War, the common sac into which both vessels open either directly or through separate orifices, as shown in Makins' diagrams, is by far the most common. In stab and other wounds the sac usually lies superficial to the artery, or on top, the orifices of the wounded vessels appearing in the floor of the sac when this is opened. In gunshot injuries the sac more often lies posteriorly, and is caused by the vessels which must be displaced in order to expose it. Therefore the classic diagrams which usually show the much rarer interposed sac should be revised.

It is not unusual to find the projectile in this communicating sac. Makins says that he has never seen an aneurysmal sac found in communication with an opening on the free side of the vein, and this is also my own experience. In every instance the traversing perforation

of the vein had cicatrized. This is in accord with what we know of the rapidly healing characteristics of venous wounds and of the physiopathology of arteriovenous aneurysm.

When the vein has been completely severed the peripheral end may heal and close while the central end remains patent, and in these circumstances the stream of blood from the artery passes directly into the open end of the vein.

Extended experience has made Makins doubt whether an arteriovenous aneurysm ever develpos as the result of the *complete* severance of the two vessels. In most of the cases in which a complete separation appears to exist the ends of the torn artery are still held together by a communicating strand or band which has prevented the artery from retracting, and acts as a guide to the current from the proximal to the distal end. The persistence of the peripheral pulse after the supposed complete sections of the vessels is due, Makins believes, to the persistence of this connecting link which guides the flow to the distal vessels. "It appears evident that the very great majority, if not all arteriovenous aneurysms, result from either lateral wounds or traversing perforation of the vessels." It is also to be noted that while the aneurysmal varix is usually an immediate development, it is sometimes days or even weeks before the arteriovenous aneurysm of the varicose or mixed type can be diagnosed with certainty. In this way the diagnosis of the double injury of the vessel is often delayed. This delay is accounted for by the presence of clot in the hematoma which, coagulating in mass under tension, compresses the injured vessels, interfering with their circulation, or by plugging the opening in the vein by a thrombus, a foreign body, shell-fragment, shrapnel, etc. The differences between purely arterial and arteriovenous aneurysms from the prognostic and operative point of view have all been fully discussed in Vol. V, p. 290 *et seq.*

THE SYMPTOMATOLOGY AND DIAGNOSIS OF VASCULAR LESIONS IN WAR

In many ways this feature of the traumatology of the blood-vessels has been notably enriched by the experiences of the late war. We shall only call attention to the more important of these acquisitions.

Local Signs.—In an open wound occurring in a vascular tract which is bleeding profusely, or which is followed by the rapid development of a diffuse and progressive hematoma, the diagnosis is clear. Where there is a small wound crossing the track of important blood-vessels, such as is observed in wounds caused by small projectiles which perforate a limb, and which are followed by little or no external hemorrhage, nor a pulsating tumor, the positive diagnosis of an arterial wound assumes a different aspect and often becomes a perplexing problem. The alterations in the peripheral pulses, their diminution or suppression, are suggestive but not conclusive, not even when they are accompanied by all the signs of a marked ischemia of the peripheral parts for reasons that we shall explain later. More often the pulses may present no ap-

preciable changes. It is under these circumstances that the greatest assistance is rendered by the signs furnished by auscultation at the site of the injury, and along the vascular tracts, as well as at the heart itself. In 1909 we laid special stress upon the diagnostic importance of the systolic bruits heard at the seat of arterial injuries—von Wahl's murmur (1880), Vol. V, p. 108, and the vast experience of this war has only served to emphasize its value and importance. Makins, who has given the closest attention to this subject, now writes (1919): "It is not perhaps, even now, generally recognized that a local systolic murmur is the most certain and easily obtainable proof of a wound of a deeply situated artery," and the most experienced surgeons of the war agree with him in this statement. This systolic murmur must not be confused with the double bruit and venous roar which is peculiar to arteriovenous lesions; it is associated with these when arteriovenous aneurysms exist, but it is inherent and common to all wounds which penetrate the arterial lumen. A bruit may be heard over a contused wound or over one in which the lumen is constricted from any cause (cicatricial contraction, pressure from without caused by compressing clot, scar, bone, or suture of an artery); but the presence of the typical systolic bruit is exceptional in such cases, and is, as a rule, indicative of a wound in an artery opening into the perivascular tissues (*vide* especially Krecke, Münch. med. Woch., 1917, 64, 991). These murmurs vary considerably in their tone and character, "a soft bellows murmur, where there is a great swelling of the limb, a loud whistling sound, a musical whistle, the latter commonly in the later stages when cicatrization is advanced. In arteriovenous lesions either the systolic bruit or the venous roar may be the more prominent element. In some cases the buzzing sound compared to the noise made by a fly or a bee in a paper bag, or a 'propeller noise,' is the salient feature; in others a venous roar assumes the character of a deep pedal note. No characteristic difference has been observed between the murmurs accompanying a contused wound produced by the passage of a bullet and the often comparatively clean-cut opening caused by a sharp fragment of shell or bomb; neither does the loudness of the sound compare with the size of the vessel concerned, although a superficial position of the vessels is of much importance in this respect" (Makins).

In purely arterial lesions the murmur is loud and is transmitted more widely in the distal than in the central direction. Certainly it is rare to be able to trace the sound more than a few inches. Further, the murmur is practically limited in distribution to the line of the vessels themselves. The presence of the systolic murmur by itself always indicates the existence of an arterial lesion and, furthermore, that the lumen of the artery is not completely occluded, or at least that an active circulation is going on through the main tract. The suppression of this murmur, after it has been once heard, indicates either the wound in the vessel has healed and the lumen completely restored, or that the circulation in the artery has been completely suppressed. This murmur must not be confused with the hemic bruits which are caused by

profuse hemorrhage and acute surgical anemia, and which may be heard over a hematoma, and at the heart, where they usually are loudest. "The pistol shot (Osler) and water-hammer" bruits which may at times be heard over all the great blood-vessels are distinct sounds, but modify the character of the murmur heard over a hematoma or a wounded artery. This murmur is heard over the heart and blood-vessels independently of any injury, and is most pronounced in preagonic conditions, in patients dying of acute toxemia, or at the end of long and trying operations in which much blood has been lost. In this form Makins compares the sound "to the falling of drops of water into an empty tube and causes an actual shock to the auscultator's ear-drum with each beat of the pulse." When this sound is present it naturally accentuates and modifies the local murmur audible over an arterial wound or aneurysm. Its importance is due to the fact that local systolic murmurs may assume the pistol-shot or water-hammer quality under the same conditions; but it can be excluded by its presence in other parts of the arterial system which are not involved in the wounded territory.

THE DUPLICATION AND TRANSMISSION OF ARTERIAL TRAUMATIC MURMURS TO THE HEART

A most remarkable observation, which is again largely due to Makins' careful study of the auscultatory phenomena of vascular injuries, and perhaps his most original contribution to their symptomatology—is the reproduction in the heart of the systolic murmur heard over a wounded artery (Makins' murmur). This appears to be a well-established fact, and as an addition to our diagnostic resources deserves special consideration. Availing ourselves of the data furnished by Makins, we find that among 180 cases of arterial lesions in which a routine examination was made, with the object of searching for cardiac murmurs, these were present in 37; 18 of the lesions were arteriovenous and 19 purely arterial.

That these murmurs are transmitted through the vessels from the site of injury to the heart can scarcely be questioned, but *how* is the problem. They usually appear coincidentally with the wounding of the vessel, and continue so long as the murmur exists in the wound; therefore the cardiac bruit persists so long as the circulation continues in the injured artery, and ceases when either the circulation in the artery is completely arrested (as by ligature or thrombus), or when healing has completely restored its lumen and permeability. While the cardiac murmur may sometimes be delayed in appearance for a day or two, it continues with variations, diminishing with rest and increasing with the activity of the patient. It is usually heard loudest at the apex, then at the base of the left ventricle, and is not conducted to the axilla or the neck. When present, the murmurs are loud and distinct and are indistinguishable in character from those of mitral valvular disease. They have been often confused with organic valvular and hemic murmurs; but when such murmurs are heard at the heart of wounded sol-

diers they should lead to an investigation at the seat of the peripheral lesion. In this way unsuspected aneurysms and especially arteriovenous fistulæ have been discovered even six years after an aneurysmal varix had been established as a result of a wound in the extremities. "It is in this respect that the conveyed murmurs acquire their chief practical importance, since it is obvious that their discovery may lead to the detection of a vascular lesion that might otherwise be readily overlooked, especially in the subjects of multiple small gunshot wounds."

It is also a remarkable fact that the conduction of the local systolic murmur to the heart is uncommon unless the wounded vessel is situated in the lower extremity. In only 6 out of 24 axillary aneurysms the murmur was heard in the heart; whereas it was present in 54 of 94 aneurysms of the lower extremities. Proximity of the lesion to the heart has, therefore, no apparent relation to its production. The transmission of the murmur to the heart in arterial lesions is itself not easily explained. The systolic murmur as it is produced in an arterial wound is propagated toward the periphery in the direction of the arterial current. This systolic murmur is not to be confused with the venous hum and roar that sometimes reaches the heart by transmission of the venous current. As the arterial traumatic murmur is propagated toward the periphery its duplication in the heart is very difficult to explain. Several theories are advanced by Makins, who suggests that the murmur may be mainly conducted by the vibrations of the arterial wall, and against the blood-stream, which would seem to be a fact, but not an explanation. He accounts for the greater frequency of the cardiac murmurs in wounds of the blood-vessels of the lower extremity by the more direct, straight, and gradually increasing size or caliber of the vessels from the extremities to the aorta and the heart. In the vessels of the upper extremities the difference in the curving and bending of the vessels may account for the diminished frequency of this auscultatory association. These explanations are, however, far from satisfactory, and the mechanism by which the transmitted cardiac murmur of Makins is produced still remains a mystery.

THE EFFECT OF WOUNDS OF THE BLOOD-VESSELS ON THE GENERAL CIRCULATION, ESPECIALLY IN ARTERIOVENOUS ANEURYSM

In this connection the changes observed in the heart and general circulation when important blood-vessels are wounded or injured sufficiently to create leaks in the vascular channels, are of diagnostic and prognostic significance. It may be laid down first as a physiologic axiom that any leak in a large artery which allows the blood-stream to be deviated from its normal channel into an indifferent perivascular space must be followed by a fall in the blood-pressure in the blood channels immediately below the leak. Second, that by the blood flowing into an extravascular space, which is not provided with elasticity or contractility, or a vasomotor mechanism, which are so necessary to the maintenance and regulation of the circulation in peripheral parts, an extra strain is imposed upon the heart to force the interrupted blood-stream into its normal channels.

The call upon the cardiac muscle is probably greatest during the formation of an arterial hematoma. According to physical law the large collection of blood will be maintained at a pressure equal to that of the general circulation, and the force for this extra duty must be furnished by the heart.

An arterial leak created by a wound or an arterial hematoma acts as an obstruction to the circulation which is felt by the heart and is interpreted clinically, and

first locally, by an immediate fall of the blood-pressure in the distal parts This was shown in 23 cases of recent traumatic aneurysm observed by Makins, causing a difference in the peripheral blood-pressure between the normal and the injured limb of 21.4 mm. Hg. when tested by the sphygmomanometer. This difference in pressure gradually grows less with the establishment of the collateral circulation.

When an arteriovenous communication has been established the obstruction to and disturbance of the circulation are still more serious. Here three evils follow: A great part of the arterial stream which was destined to supply the distal parts is diverted into the venous system through the communicating vein and the aspirating influence of the venous current allowing only a small part to continue on to its destination. In consequence, arterial ischemia of the peripheral parts with all its bad effects upon the nutrition of these follows. Second, the arterial current entering the vein causes this to stretch in consequence of the greater pressure of the arterial current, and a great bay is formed in which a swirling eddy is established. Hence, the venous plethora and varicosities caused by the obstructed and delayed venous current. Finally, the short circuiting of the arterial current into the vein fills the right heart with a great excess of blood under a much higher tension than normal, causing an overdistension which seriously interferes with its functions until compensatory hypertrophy occurs.

The effect of this extra strain upon the heart is to dilate it as shown by the displacement of the cardiac apex to the left, and the increase of the cardiac shadow as seen on the radiologic screen. In addition, there is an invariable increase in the frequency of the pulse-rate, which may vary from 80 to 120, with an average of 100 (Makins). Of course, this increased frequency is subject to many variations due to many obvious and extrinsic causes. The tendency to tachycardia is most marked immediately following the trauma, improving as compensation occurs, both at the periphery and at the heart.

The strain on the right heart and the secondary cardiopathy that results from the venous plethora and increased tension of the venous current from the short circuiting of the arterial stream in advanced arteriovenous lesions had been noticed long ago by many observers, and especially by Pierre Delbet, but had not been so convincingly demonstrated until recently, when Bernard Cunéo showed by manometric measurements of the systemic venous pressure in a series of 7 arteriovenous femoral aneurysms that came under his observation during the war that the normal venous pressure was increased as shown in the opposite (normal) limb and in the veins of the upper extremity (in one case nearly three times above the average normal venous pressure). He was also able to confirm what was already known, but not with so much precision, that the lowering of the arterial blood-pressure below the arteriovenous communication is a constant and unfailing phenomenon. From the point of view of their effect upon the heart and the systemic venous blood-pressure arteriovenous aneurysms may be grouped according to Cunéo's investigations (which are in full accord with clinical experience) into: (1) the simple arteriovenous fistula or aneurysmal varix (phlebarterie of Broca), in which there is only a slight and uniform dilatation of the veins, not followed by notable varicosities or venous sacculations, with practically no disturbance in the dynamics of the circulation. In these cases the valves of the veins below the site of the anastomosis have not been forced by the inflow of the arterial current and they remain resistent, so that no damming or back flow in the vein occurs. These are the well-tolerated cases, which may go on for years without causing notable or even appreciable local or general disturbances. On the other hand, the most serious damage to the heart and to the venous circulation follows in (*b*), the arteriovenous communications, whether direct (varix aneurysmaticus) or indirect (varicose aneurysm), in which a large orifice allows the arterial current to flow into the veins which soon overcomes the resistence of the valves and leads to a rapid and generalized arterialization of the veins (thickening and pulsation). In these cases sacculation and varicosities of the veins in the affected limb, with rapid and early dilatation of the heart, occur. In some cases the general systemic effect of the lesion is noticeable shortly after the injury; in others the cardiopathy comes on slowly and gradually becomes progressively worse (tachycardia, dyspnea, asystolic crises, precordial distress) until the patient is completely disabled. An extreme case of the arteriovenous cardiopathy from venous overstrain (*cœur forcé*) is reported by Toussaint, who relates the case of a French officer suffering from an arteriovenous aneurysm in Scarpa's triangle who had become virtually inoperable in consequence of the cardiovascular changes which had followed the establishment of the lesion. The advisability of amputation on a level with the aneurysm was brought up as a possible means of relief in such an advanced case, and was suggested by Toussaint, who regarded the amputa-

tion as less hazardous than an attempt to extirpate the aneurysm or to suppress it by quadruple ligature. The serious effects of this cardiovenous hypertension are well illustrated in a number of cases of advanced arteriovenous aneurysms operated by myself. (See Annals of Surgery, April, 1920.)

The lessons gathered from these recent observations all point to the fact that the reputed benignity of arteriovenous aneurysms is more relative than actual, and that the systemic effects of arteriovenous aneurysm should be studied more closely than in the past. Once these effects are recognized, an early intervention is indicated before the compensatory mechanism (valvular and cardiovascular) breaks down. In general terms, the systemic effects of arteriovenous lesions are dependent upon: (*a*) the *size* of the arteriovenous communication, (*b*) the volume and force of the arterial stream that is short-circuited into the communicating vein, (*c*) the caliber of the vessels involved, (*d*) the proximity of these to the hematoma. Of the accessible or surgical aneurysms, those of the iliac and femoral, axillary, subclavian, and carotid tracts are, therefore, most likely to establish these systemic reactions. The fatal effects of the arteriovenous communications between the caval and aortic trunks have been well demonstrated, especially by Carrel (Vol. V, p. 299). But the extraordinary capacity of the heart to adapt itself to a reversed circulation, even between these great vessels, is shown by the greater or less period of survival in many of the cases (as long as ten months—Luton) quoted by Boinet and others.

Locally the blood-vessels undergo marked changes which are most notable in advanced arteriovenous lesions. These I have fully described under Arteriovenous Aneurysms, Vol. V, Chap. LXX. The cardiac disturbances are most marked in arteriovenous lesions. These changes have been noted by all observers of large experience and play a considerable part in postoperative sequelæ, especially in those in which the injury is of ancient date. In one case of arteriovenous aneurysm of the femoral vessels of three years' standing operated by the writer, the restoration of the circulation to its normal channels was followed by an immediate tachycardia in which the pulse rose from 90 to 200, and continued at this rate for over twenty-four hours after the operation. In every other case of some standing the operation for arteriovenous aneurysms has been followed by immediate postoperative rises in the pulse-rate which was always a cause of alarm or anxiety at the time. This postoperative tachycardia of the old aneurysms is accounted for by the sudden production of a minus tension in the right heart and a plus tension in the left, consequent upon the restoration of the arterial current to its normal peripheral channels. These circulatory and cardiac disturbances are almost certain to follow operations upon arteriovenous aneurysms of long standing of the larger vessels, and in which the circulation has been restored suddenly to normal by the closure of the artificial arteriovenous communication. This fact accounts in part for the comparatively little attention that has been paid by surgical writers in the past to these cardiovascular disturbances, which have only come to light as postoperative phenomena since the restorative operations have become more frequent.

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THE DIAGNOSTIC INTERPRETATION OF THE PERIPHERAL PULSES IN VASCULAR LESIONS

The distal or peripheral pulse in wounds involving the main artery or the limb may remain unaffected and apparently *normal*, or be *diminished, retarded*, or *suppressed*. The peripheral pulses may seem to be normal, and still a vascular injury may exist. When the pulse is diminished in volume it strongly suggests that the vessel has been injured. When the pulse is delayed it suggests the presence of an arterial hematoma or traumatic aneurysm. When suppressed it means, as a rule, that the vessel has been completely divided or completely blocked by a thrombus. The preservation of the peripheral pulse, notwithstanding a recent wound of the parent vessel, is not an uncommon phenomenon, as has been shown by many observers (Fiolle, Duval, and others). This is no doubt accounted for in most cases by the rapidity with which the collateral channels restore the circulation in the main artery below the lesion. But this does not appear to be the only explanation. Mondor has shown that the preservation of the peripheral pulse in spite of a wound

of the main artery is indicative of a *lateral* or *incomplete* division of the artery; the blood finding its way to the peripheral end as long as the channel is *partially* preserved; that it is the persistence of this channel that allows the pulse to remain is shown by the fact that the pulse is immediately suppressed when the injured artery is ligated above and below the arterial wounds. In injuries of the brachial artery the radial pulse thus suppressed will reappear in 80 per cent. of the cases after the lapse of three to ten days. It is this secondary or resurrected pulse that is due to the collaterals. It is then understood that the collateral circulation is established immediately, or long before the appearance of the peripheral pulse, and is amply sufficient for all nutritive purposes. But the appearance of the pulse after the obliteration of the main artery by ligature, or otherwise, means that the collateral routes have been more perfectly organized, and that the blood-stream has found its way back into the main channel. It is this persistent peripheral pulse following vascular injury in a wound in which all other characteristic signs are missing—hemorrhage, hematoma, vascular bruits, etc.—which constitute the so-called group of "dry" wounds, "*plaies seches*" of the French, that is at times misleading. While the cases in which the systolic von Wahl bruit is missing must be very few indeed, the explanation that the persistent peripheral pulse is indicative of a lateral wound of an artery, and that its *immediate* suppression after the injury with no other signs is indicative of a transverse section of the artery, is of some value. Special stress has been laid by Mondor upon this differential peculiarity, and its significance is well worth remembering.

Mondor has also called attention to the importance of diffuse ecchymoses and subcutaneous extravasations (not hematomata) in cases in which these dry, symptomless gunshot wounds occur in the track of injured blood-vessels. In these cases there is no hemorrhage, no hematoma, no modification of the peripheral pulses, nothing but very *large surface ecchymoses* in the neighborhood of the wound track. If such is the case, the ecchymosis is itself strongly suggestive of a wounded blood-vessel.

Sencert has also called attention to another clinical type of "dry" wound in which there is no hemorrhage, no hematoma, no alterations in the pulse, no ecchymoses, but in which there is a local pain in the track of the wounded vessel, and a functional weakness, disability, or helplessness of the injured limb that is out of all proportion to the extent of the injury. In these cases a careful exploration of the wound will usually reveal an arterial wound. This syndrome would constitute the Sencert type of blood-vessel injury in which notable pain on pressure in the vascular tract and exaggerated disability are the dominant characteristics. It is a question yet whether in these rare types of dry wounds sufficient attention has been given to the auscultatory signs. Comparatively little allusion is made by Mondor and Sencert to the search for the systolic bruit, and to whether it was present or absent in their observations. In view of the almost unfailing presence of this sign at the seat of an arterial injury, it should always be sought for, and more particularly in the obscure cases of the Mondor and Sencert type.

Interpretation of the Pulse in Nerve Injuries.—The radial pulses and the peripheral pulses in general are appreciably smaller in all paralytic lesions of the extremities. This is especially notable in total brachial plexus paralysis and is caused by inactivity of the arm; the impulse given to the circulation by the skeletal muscle is missing, and the diminished stimulation of the neuromuscular mechanism of the vessels is also missing. The blood-pressure on the paralyzed side may fall as low as nearly half that on the normal side: 85–125 mm. Hg. systolic pressure. Several months must elapse before the blood-pressure is equalized on both sides (Thöle). The loss of tone or tension in the blood-vessels is proportional to the degree and extent of the paralysis and is independent of any complicating vascular injury. This loss of tone or tension is not constant, and, in fact, may be absent in many cases of brachial paralysis.

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PSEUDO-ANEURYSMS AND THE THRILL OF ARTERIOVENOUS ANEURYSMS

The experience of the war has brought out that our views on the thrill—"the bubbling thrill," "the purring thrill" of English writers, the "fremissement vibratoire or cataire" of French observers, which has justly been considered hitherto as

pathognomonic of the arteriovenous aneurysms—must be revised, as we have learned that it may be reproduced under conditions, rare it is true, in which there are no arteriovenous lesions or even any vascular lesions at all.

For many years isolated observations have been published by various writers describing conditions in which the thrill and characteristic murmurs, machinery bruits, etc., were present, and in which the most careful dissection and exposure of the parts in the course of exploratory operations failed to reveal the presence of any anatomic lesion of the blood-vessels. These cases have been described by several writers (Dobrowlsky, Neugebauer, Kuttner, Kredel, von Oppel, and others) as *pseudo-aneurysms*. More often these thrills have disappeared when a compressing tumor was removed, the vessels remaining normal, simply relieved of compression or angulation, or overstretching which narrowed the lumen (P. Duval, Delbet, Tuffier, *et al.*). In others, secondary operations have demonstrated that arteriovenous anastomoses did exist which had escaped detection in previous operations, and if these were not present other abnormalities in the vessels were found which seemed to account for the thrill and of normal sounds, though typical arteriovenous anastomoses could not be demonstrated. Bérard and Dunet, who gave a very careful study to the conditions that form the aneurysmal thrill, arrive at the following conclusions: (1) The thrill is a clinical phenomenon which is accounted for by the passage of the blood-stream through a contracted orifice or canal, connecting two cavities in which different pressures prevail.

The thrill is not exclusively a mechanical phenomenon; it is also a vital phenomenon attributable in great part to the active contractility of the arterial tunics.

(2) The existence of a contracted orifice or canal, as above described, is met in arteriovenous anastomoses and fistulæ and also at times in exclusively arterial lesions.

A. In arteriovenous lesions the orifice of communication between the two vessels can be demonstrated to be the cause of the thrill by its disappearance immediately upon obliterating this orifice by pressure.

B. Arterial lesions: The reduction or contraction in the caliber of an artery may be due to two different causes: (*a*) extrinsic—compression by tumor, bone growths, enlarged glands, cicatricial bands, and kinks. (*b*) intrinsic—a parietal lesion of the vessel whether traumatic or not, which irritates the perivasal, sympathetic plexus, causing a reflex angiospasm.

(3) The thrill of an arteriovenous lesion is as permanent as the lesion itself. It is associated with a continuous murmur, with systolic reinforcements, the systolic bruit being conducted along the course of the artery, peripherally; whereas the venous roar or hum is conducted along the vein, centrally.

(4) The thrill which is felt in arterial lesions (without venous anastomosis) varies in duration with the nature of the causative agent. It will remain permanent if it is a tumor until this is removed; it will be transitory if it is due to angiospasm. In this case it may also be associated with all the auscultatory phenomena previously described, thus simulating all the clinical phenomena of an arteriovenous lesion, but with no appreciable organic lesion whatever.

Walther contends, and I believe correctly, that while the "thrill" may be imitated by other conditions—pressure stenosis in which there is no actual arteriovenous communication—it still remains a pathognomonic sign of arteriovenous aneurysm whenever the thrill is accompanied by a systolic intermittent murmur or a continuous blow which is reinforced or accentuated by the systolic wave. As long ago pointed out by Tillaux, the existence of the systolic intermittent bruit reinforcements is the differential feature of the arteriovenous thrill as distinguished from the pseudo-aneurysmal thrill of compression or arterial stenosis. In the discussion that followed Tuffier, Hartman, Broca, and Pierre Delbet gave the weight of their testimony in favor of this differentiation.

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SECONDARY HEMORRHAGE

In disposing of this gravest of all the sequelæ that follow in the wake of vascular wounds we find that no extraordinary progress has been

made in its actual treatment in the present war. The conditions that bring it about in war wounds, as well as in civil practice, have not changed, and its surgical treatment when it makes its appearance is governed by practically the same rules that have guided the surgeon in modern wars. On this particular phase of the subject there is little to add to the text that will be found in Vol. V, p. 85.

But while no extraordinary developments have added to our knowledge of the causes, pathology, and treatment of secondary hemorrhage, the history of the present war may claim for surgery one of its most brilliant achievements in the *prevention* and control of this dreaded complication. We have learned that primary wound sterilization by excision of the devitalized and contaminated tissues is the keynote to the prophylaxis of infection, and in this way the mortality from secondary hemorrhage has been reduced as in no previous war.

The elimination of infection by the technic of wound excision is, therefore, the greatest factor in the preventive treatment of secondary hemorrhage. After the adoption and systematic application of this technic to all war wounds, and especially the invariably septic wounds caused by artillery projectiles, secondary hemorrhage has become practically a negligible complication in vascular war wounds. But it would be unfair to attribute the great reduction in the mortality from vascular wounds, since "débridement" became generalized, to this cause alone. There can be no doubt that a prophylactic influence has also been exercised in warding off this complication by the better methods of antiseptic wound treatment in infected wounds which come to the surgeon too late to benefit by primary excision in the incubative stage of wound contamination. The prophylactic treatment of secondary hemorrhage, therefore, includes not only the prevention of infection by surgical excision, but its control by germicidal agents when it actually exists. In this respect the chlorin compounds stand foremost among the agents which have been found most efficient in arresting infection, and have a proper claim to recognition in the prophylaxis of secondary hemorrhage by wound disinfection.

In regard to the local treatment of this form of arterial bleeding, and apart from the germicidal and surgical methods employed to combat the infection, all surgeons are unanimous in recognizing the prime importance of dealing with the bleeding vessels in the *wound itself*, and that the ligature of the blood-vessels in continuity or at the *point of election* is, as we have had occasion to point out repeatedly in Vol. V, not only fallacious in its protective value against hemorrhage, but most dangerous to the integrity of the limb. The fallacies underlying this practice have been brought out in practically every communication that has been published on the subject, and notably in the transactions of the Societé de Chirurgie when secondary hemorrhage was thoroughly discussed in November and December, 1914, early in the war. It was at that time that Thierry, calling attention to this growing evil, appealed to his colleagues for suggestions in its treatment. This led to a volume of communications in which many surgeons related a multi-

tude of personal experiences which showed how prevalent and grave this complication was. The discussion also emphasized that the chief reliance of the surgeon had to be placed in the *direct control of the bleeding in the wound itself*. Bleeding granulations and parenchymatous or capillary hemorrhages had to be cureted and excised until the living healthy planes of tissue were reached. When large or small vessels are found bleeding they must be secured in the wound above and below the bleeding point, and only when this is absolutely impossible to accomplish the vessels should be secured above and below the infected focus, but *always as near the wound as possible*. Only as a last and desperate resort the ligation at the point of election should be done. In view of the great danger from gangrene of the distal parts from this procedure, amputations should be resorted to early, before the strength and resistance of the patient has been completely exhausted. Tampons and local hemostatic applications could only be resorted to as purely temporary expedients, pending more direct surgical action. The adoption of larger incisions for the exploration and exposure of the bleeding trunks above and below the wounds became necessary under these conditions, and the modifications brought about in the operative technic to meet the requirements of these wounds in the control of bleeding vessels in general are well shown in the new manual developed by Duval through his pupils, Fiolle and Delmas. Sencert, in his excellent manual of war wounds, and Makins, speaking from British experience, and Giovanni, speaking for the Italinan surgeons, and Kuttner, for the Germans, all unite in advising the ligature of the vessels in the wound at the seat of the bleeding above and below the bleeding point, and agree in condemning the ligation of the main vessel at a distance. Exception to this rule is made in septic wounds of the upper neck, submaxillary region, jaws, and oropharynx, where the bleeding point is practically inaccessible and is constantly bathed in the foulest secretions. In this region the ligation of the external carotid, outside of the infected area, has always yielded excellent results, and should be applied unhesitatingly as a primary measure. The gluteal region is also the seat of secondary hemorrhages from the gluteal artery which are most difficult to control at times with a ligature, and for which the intraperitoneal ligation of the internal iliac is the only remedy. In dealing with secondary hemorrhage in amputation stumps the ligation of the main vessel is specially successful, and is thoroughly justifiable.* There are hemorrhages in regions outside of the extremities, at the root of limbs and in the neck, where prophylactic provisional hemostasis by

* "In all open, septic stumps in the thigh which are a week or more old, I make it a routine practice as a preventive measure, to ligate the common femoral vessels. By the end of the first week after the amputation the collateral circulation, after ligation of the common femoral, is ample for the needs of any stump down to the supracondylar level. For open stumps below that level, certainly for those below the knee, ligation of the femoral in a septic limb carries with it a grave risk of resulting gangrene. Fortunately, the need for it in such cases is less frequent than in thigh stumps. In the latter secondary hemorrhage becomes too often a tragedy. In leg stumps the flow is much less copious (from one only of these vessels), and gives time for the nurse to apply the tourniquet or compress the femoral until surgical relief is obtained" (Nicoll, Brit. Med. Jour., vol. 118, p. 569).

constriction cannot be applied, and in which even the supreme resource of amputation is denied. Septic patients, exhausted and exsanguinated by previous hemorrhages, shock, and toxemia, are unfit for any sort of serious operation which would require general anesthesia. Under these circumstances hemorrhage can only be primarily controlled by one of three ways (tampon, forceps, ligature), none of which is either ideal or desirable, but become procedures of necessity in the presence of impending death from hemorrhage. In these special emergencies digital direct compression of the bleeding point in the wound is the first step; then an effort must be made to secure the vessel at the bleeding point with a hemostatic forceps, which, if it can be made to hold, should be left in place and supported with a pack and dressings. If the forceps will not hold, the massive through-and-through suture of the bleeding area, including the perivascular tissues, with a strong, curved needle and silk, should be carried around the bleeding vessel and bleeding spot as often as may be necessary to control the bleeding. In order to do this effectively the wound must be exposed freely. If the bleeding is checked and the condition of the patient will permit, the wound can be cleansed and cureted if necessary to clear it of infected granulations, sloughs, etc., after which dichloramin-T or Morison's bipp (if the wound cannot be dressed frequently), or, if the patient is in favorable surroundings, the Dakin-Carrel treatment should be instituted.

In endeavoring to control bleeding vessels in septic foci the use of ligatures or occlusive material that is not hygroscopic or chemotactic for bacteria is desirable. Catgut and other organic material and ordinary silk or linen ligatures soon become saturated with the bacteria of the wound and act in the end as septic setons which cut through the vessel with great rapidity. Under these circumstances I have found that the best material is a narrow aluminum band which can be adjusted to a bleeding vessel more easily than a ligature, and has the advantage over this that it is always sterile and impenetrable to bacteria. Cushing's silver clips may be used for the smallest vessels, but heavier aluminum bands for the larger vessels. When only silk ligatures are available, they should be iodinized thoroughly in alcoholic tincture of iodin and then immersed in sterile melted paraffin. I have found that paraffin wax, such as is used for burns, in Hull's formula Number 2 (*vide* Surgery of Burns) is most valuable in retarding, at least, the ulcerative action of the ligature as it occurs in septic foci. This advantage is due to the non-hygroscopic, negative chemotactic qualities of the thread after it has been waxed in this way.

In the most desperate cases nothing can be done but pack the wound. It is then also very desirable that the material used for the pack shall resist decomposition as long as possible. For this purpose dry iodoform gauze which has been previously soaked in compound tincture of benzoin is preferable, as it will keep comparatively sweet even in foul cavities for a longer time than any other material. It is essential, of course, that in tamponing such wounds the pack shall really compress the bleeding point. It is of no use to pack gauze through a small

aperture into a big lacerated cavity. If the aperture is small it should be enlarged without waiting for anesthesia, either local or general. The gauze is to be packed firmly into the wound, and if necessary held in place by one or more silkworm sutures. In dealing with the extremities, my large, thick, mattress pads which completely envelop the limb, and can be made to fit it snugly, are preferable to splints to secure the immobilization of the limb without risk of undue compression or pressure sores. Wounds of the neck, shoulder, or the supraclavicular regions should be immobilized with a Desault or Velpeau bandage, and reinforced with heavy adhesive strips.

A glimpse at the results obtained by the methods above described, especially by the immediate ligation of the vessels in the wound, at the front and base hospitals can be obtained by the following data:

Pierre Duval, in a statistical report of 4127 operations, states that there were only 34 ligations for secondary hemorrhage, with 5 deaths, or 14.7 per cent mortality. Another glimpse at the results obtained in the treatment of secondary hemorrhage at the base hospitals in Paris may be obtained from J. E. M. Hardouin, Paris Thesis. He collected 49 cases of secondary hemorrhage. These resulted in 40 recoveries, 6 amputations, and 6 deaths.

Neuhof and F. St. John contribute an excellent clinical and histologic study of the "Infective (secondary") hemorrhages from war wounds, based upon the careful study of 45 cases of secondary hemorrhage which occurred in a total of 5000 wounded soldiers who passed through their hands in one year (1 per cent.). Many of these cases were minor ones; others did not require surgical interference. Its incidence is, therefore, better appreciated in the statement that 65 of a total of 2332 operations were undertaken for its control (2.79 per cent.). The frequency of this complication diminished as the method of primary surgical sterilization improved. The infective hemorrhages occurred on an average of 12.8 days; the extremes were five to forty-seven days.

The Treatment of Arterial Lesions in Infective Hemorrhage in the Large Group of Cases in which Amputation is Not Indicated.—Neuhof and St. John's report shows that hemorrhage recurred in 50 per cent. of the operations, consisting in ligation or resection of the artery in the wound or amputation stump, and did not recur in any of the cases in which the artery was surgically exposed and resected in non-infected or comparatively little infected fields. The only argument they have seen advanced against ligation by surgical approach appears based upon the belief that the vessel must be ligated at a considerable distance from the wound, with the possibility of resultant devitalization. In only 2 cases of this series was high ligation performed, and it was done solely because the site of the lesion was not determined. The source of bleeding *can* be discovered in the great majority of the cases, and the resection of the artery is almost invariably made not far from the confines of the wound. Neuhof and St. John, therefore, strongly advocate the surgical approach to the artery, whenever feasible, through a separate incision, its double ligation beyond the rupture and the infected tract, and the resection of the portion between the ligatures. The likelihood of infection of the accompanying veins is so great that they should be resected at the same time unless they are important venous trunks. In the latter case examination should be made for the presence of an infective phlebitis. If this exists, the indication is clear. The authors are at present inclined to believe, for various reasons, but especially because of the probability of venous involvement, that the accompanying vein should be ligated or resected even if an important trunk.

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TESTING THE EFFICIENCY OF THE COLLATERAL CIRCULATION AS A PRELIMINARY TO THE OCCLUSION OF THE GREAT SURGICAL ARTERIES

The advantages of a preoperative knowledge of the possibilities of the collateral circulation, that is, of the behavior of the peripheral circulation in the dependent parts (extremities and brain) after the occlusion of the main nutrient artery is seemingly so obvious that to insist upon its great importance would seem superfluous.

The time has now come when every progressive surgeon must regard it as his duty to ascertain by actual tests what the behavior of the peripheral circulation will be whenever an operation is contemplated in which the parent vascular trunk is likely to be involved. This is no longer a matter for academic discussion or theoretic interest, but a subject of practical, vital, importance.

Will fatal coma or cerebral complications follow the ligation or excision of the carotid for hemorrhage, aneurysm, or the extirpation of a tumor of the neck? Will the limb become gangrenous when the popliteal, femoral, external iliac, brachial, axillary, or subclavian is ligated or excised? If such is likely to be the result according to the tests, what is the surgeon going to do about it? These are the questions that are put to the surgeon of the present, who, with means for obtaining this information, is able to exercise a discretion which was denied his predecessors. They had no alternative but to ligate when facing hemorrhage in an open or closed wound, whereas now, with new technical resources at his command, he may often choose his methods according to local conditions.

Freely granting that the exigencies of the battlefield and field hospitals often preclude the possibility of applying such careful and repeated tests to the collateral circulation as are practicable in the less urgent and tranquil conditions of civic practice or at the base and home hospitals, and granting also that no test, no matter how satisfactory it may be at the time of its performance, can foretell that a secondary thrombus may or may not develop and spread from the seat of ligature, a suture, or an intubation, and thus negative the results of his investigation—this is no reason why he should not satisfy himself of the conditions existing at the time. Clearly he is not responsible for accidental conditions which may develop irrespective of the operation, and which are common to all injuries of the blood-vessels. These, however, are rare and exceptional, and not in the least necessary sequels to an operation.

If the tests show that after a temporary occlusion of the injured vessel the limb remains pulseless, cold, colorless, cadaveric in spite of heat, massage, and other practices to rouse the peripheral circulation, it is plain that he should heed this warning and put off the operation; but if this is not possible, he should adopt every available means that will tend to restore the continuity of the leaking vessel. On the other hand, if the tests show that the collateral circulation is quite competent to sustain the nutrition of the distal parts, the labor and time required

to establish a successful end-to-end anastomosis is unnecessary. A quick and simple ligature will suffice to meet the most pressing indications. That many superfluous and unnecessary circular sutures, with and without venous grafts, to bridge over missing vascular segments have been applied during the war and previously, cannot be doubted. In many the pulses appear to have been delayed; in others the existing pulse has been suppressed shortly after the suture; in others they have not returned at all. Still worse, in some cases there were no peripheral pulses when the operation was performed. In these various conditions when the limb has survived (as is more often the case) the burden of the peripheral circulation has been carried by the collateral vessels and not by the main artery. In other words, an anastomosis may be successfully performed, and be an operative success, and yet prove a total physiologic failure. This is particularly true of the interposed venous grafts which have proved so unreliable that they have been virtually abandoned, at least for war wounds. I shall again refer to the relative merits of the suture and other conservative methods, as compared with the obliterative method, when we come to the treatment of traumatic aneurysms.

What I contend is that the impetus given the technic of vascular suture and plastics in experimental laboratories has prompted many surgeons in this war to resort to arteriorrhaphies without sufficient discrimination, and have been led to the performance of many difficult and uncertain operations, which could have been dispensed with if the resources of the collateral circulation had been previously ascertained.

On the other hand, the older surgeons have been equally at fault in ignoring the importance and value of the tests of the collateral circulation, thereby falling into serious and fatal errors in operations which could have been avoided or modified by a proper study of the actual resources of the collateral circulation before attempting an operation.

In dealing with open wounds, as in the course of a débridement when the wounded blood-vessel is exposed, and after the thorough surgical cleansing of the wound has been completed, the means of testing the efficiency of the collaterals are quite limited and lose all the advantages that obtain when the tests are applied as a *preliminary* to the operation, as in dealing with circumscribed hematoma or aneurysms. In facing the latter group of cases, if the reactions of the periphery are not satisfactory when the main artery is occluded, the operation can easily be delayed until the collaterals can be trained, as it were, by various exercises and treatments, both local and general, which tend to develop them. In the great emergencies of war there is no time for delay; the operator must arrive at conclusions while the wounded vessel lies exposed before him. Often no tests will be required to tell that the dependent parts are on the brink of mortification from local anemia, and that the restoration of the blood-channel is imperative. More often there is reason to doubt the issue, and it is then that the tests will help to clear his doubts.

The great frequency of vascular injuries in the Russo-Japanese

War, with gangrenes as a consequence, incited Korotkow, of St. Petersburg (1905–06), to investigate the behavior of the collaterals as a preliminary to the occlusion of the great arteries in operations for aneurysm. He deserves great credit for his pioneer efforts which were put to practical use by Petrov (1907), Fedoroff (1907), and especially by von Oppel (1908), who made their results known to the German surgical press long before Korotkow's original paper was published. An account of Korotkow's methods was given in Vol. V, Chapter LXX, p. 273, and I have entered more fully into the reasons why I, who was then (1907–08) devoting much attention to the subject, found it advantageous to substitute other procedures for the tonometric and sphygomanometric methods of Korotkow. From that time to the present I have always studied the behavior of the collaterals as a preliminary to all operations for aneurysm or other conditions which might involve the carotid, subclavio-axillary, brachial, iliac, and femoropopliteal tracts. My publications during the last thirteen years give an account of my activities and attest to my convictions which a larger experience has only served to confirm.

The Balkan campaign (1913–14) with its abundance of vascular wounds brought several new tests, chiefly suggested by German or Austrian surgeons, which were calculated to meet the requirements of primary injuries of the blood-vessels. These tests have been tried with variable results, and have been made the subject of much discussion by the German surgeons in the present war. The most prominent of these tests are the Henle-Coenen, the von Frisch test, and the Moszkowicz hyperemia reaction, which had been insistently advocated and resorted to by myself since 1907, long before the war had given it the prominence it now has in German literature.

The Henle-Coenen Test (1912).—This test, which was suggested by the experience of the Balkan campaign, is only applicable in the course of the operation. Coenen notes first the *color* of the extremity, after temporarily occluding the artery, just above the wound, or of the aneurysm, and tests whether bleeding takes place on incising the fingers or toes. This practice was advocated long before by others. His (Coenen's) specific test, however, is as follows: "The aneurysmal sac is dissected out without the preliminary application of an Esmarch bandage, and the artery is closed temporarily above and below the aneurysm, and as close to it as possible. A second clamp is then placed on the efferent or distal side of the vessel, beyond the first distal clamp, and the artery is cut through between the two. The distal clamp is then released, and if bleeding occurs, it is presumed that the collateral circulation is ample, so that a ligature may be safely applied. If there is no bleeding, the sac is excised and a circular arteriorrhaphy is in order. Instead of cutting the artery, the sac may be simply laid open, and after finding the position of the outlet and inlet, if bleeding occurs from the outlet or efferent orifice while the artery on the cardiac side is clamped, it shows that the collaterals are efficient, and the sac may be excised and the arteries ligated. When there is no aneurysm, and only a divided vessel, the same principle applies: if free bleeding occurs from the distal side while the proximal end is occluded, it is presumed that the collateral circulation is established and that ligation is safe." The fallacies that underlie this procedure will be referred to later.

Von Frisch's Signs.—Frisch while working in the Balkans also depended upon three signs, one of which is alone original with him. This test is also applicable only in the field of the operation. According to this observer, if the proximal side of an injured artery is provisionally occluded, the efficiency of the collateral circulation can be demonstrated by the following three signs: (*a*) Normal, or approximately normal color (living, as distinguished from cadaveric color) of the dependent pe-

ripheral parts. This sign had been previously insisted upon by myself in 1907 and by Coenen (1913), by Moszkowicz (1915), though the last named author had originally called attention to the color reactions of the skin, after artificial ischemia, in determining the line of amputation for gangrene in 1907. (*b*) Arterial hemorrhage from the peripheral end of the injured vessel (the Henle-Coenen sign). (*c*) Venous stasis below (peripheral side) of the clamped *main vein in the wound*, followed by cyanosis and turgescence of the peripheral veins, while the artery is also clamped above and below the wound. This third sign is the one upon which Frisch lays particular stress. The test in a modified form is identical in principle with that described two years previously by Tuffier and Hallion (1912).

Tuffier-Hallion Test.—A circular band or elastic cord, which may be easily tightened or relaxed, is made to encircle the extremity at the part desired, for instance, at the ankle above the malleoli, when the foot is under observation. If the band is tightened it will compress the superficial veins and thereby interfere with the returning circulation, causing a marked turgescence and swelling of the veins of the foot. The flow through the arteries will not, however, be interfered with. If this maneuver is repeated while the main artery of the limb (the lower femoral) is compressed, the veins of the foot will swell only on condition that sufficient arterial blood is brought to the foot by the collaterals. If this turgescence does not occur, there is no collateral circulation, and vice versa.

A great many German surgeons have resorted to the Henle-Coenen and the Frisch signs (more particularly the former), but the opinions expressed are far from being unanimous in its favor. Frisch himself denies the value of the Henle-Coenen sign, since bleeding from the distal end of the artery, either in a sac or when exposed in a wound, comes from the extreme periphery of the limb. He proposes, as previously stated, that the companion vein should also be isolated and clamped. If this becomes markedly distended distal to the clamp, he looks upon it as a positive sign of the efficiency of the collaterals, since the blood can only reach the vein via the collaterals. There is no doubt that the objection to both the Henle-Coenen and the von Frisch signs, when performed as directed, is that the blood may be short-circuited through the collaterals in the immediate neighborhood, and so never come from the extremity of the limb at all. On the other hand, if the limb to be tested is previously completely exsanguinated by elastic compression (Esmarch) and then the main artery and vein are both clamped in the wound the color reactions in the limb and congestion of the veins will be decidedly significant, as they follow the removal of the elastic bandage. The turgescence of the superficial veins and cyanosis of the limb at the foot or hand, as the case may be, will indicate that the collaterals are responsible for the filling and congestion of the vein. The congestion and swelling of the surface veins will be made more apparent by applying the circular rubber string to the ankle or wrist, as the case may be.

Another objection to these tests is that in depleted, exsanguinated subjects, in whom the blood-pressure is very low, the filling of the veins even with a fairly open collateral route is likely to occur slowly, and, in this way, time consuming and disadvantageous in emergencies.

To meet these objections Moszkowicz (1915) proposes the hyperemia reaction which we shall consider later, as it has been the basis of my own testing in all traumatic hematomas and aneurysms.* At the present time the **Pachon sphygmomanometric oscillometer** (p. 780) is likely to take the place of all instruments previously devised to determine the activity of the peripheral circulation in the extremities, to which alone it is applicable. Applying it as a preliminary to operation, as in cases of aneurysm, the main arteries should be compressed, preferably with a mechanical compressor that will control the vessel without interfering with the collaterals, such as my caliper-compressor (Figs. 328–330).

This exceedingly sensitive instrument invented by Pachon (Paris, 1909), apart from its sphygmomanometric value as an indicator and recorder of blood-pressure, owing to the great sensitiveness of the oscillometric needle, is very reliable as a means of exploring the peripheral circulation. Its chief value in this respect lies in its sensitiveness to the slightest pulsation. Its surgical application has been especially studied in France in the last few years not only in the pre-operative exploration of the peripheral circulation, but subsequently in a prognostic way to determine the effect of a ligation, suture, or intubation of an injured or diseased blood-vessel (arteriosclerotic and thrombotic obstruction). I called attention to this instrument in June, 1914. A summary of the latest literature will be found in an excellent paper by P. Balard and in a "Rapport" by Tuffier. This is of special value in con-

*Matas: Jour. Amer. Med. Assoc., Oct. 24, 1914.

nection with vascular war wounds. See also the Jour. Méd. Français, Sept., 1919, which is wholly devoted to articles on oscillometry by the Pachon instrument. (See supplementary note describing the Pachon instrument, p. 780.)

There are a number of other valuable clinical signs and tests, such as the "Delbet sign,"* Bégouin and Moulinier's† "Signe des collaterals," etc., which are helpful to the surgeon in determining whether the collaterals have developed efficiently or not, but these special signs are applicable to cases in which aneurysms or other obstructions to the circulation have existed for some time, and are scarcely applicable to recent war aneurysms.

Other valuable methods of testing the collateral circulation have been devised by Prof. Stewart, of Cleveland, "Stewart's calorimetric method," and by Hallion, with a volumetric plethysmograph. These and other laboratory devices I have described in other publications.

Matas' Methods.—A description of these methods is best presented by summarizing the account I gave in a paper read before the American Medical Association in June, 1914:

I would now renew attention to the simple methods of testing the collateral circulation which I devised in 1907, and have adopted in my practice since that time with increasing conviction in their reliability, simplicity, and general utility. These tests I have found to be of the greatest value in determining the indications for my obliterative, restorative, and reconstructive operations for the cure of aneurysm, and no patients are now operated on in my clinics without a preliminary and systematic study of the circulation by means of these tests. These methods require two procedures according to the region involved and the artery to be tested:

(*a*) **The Hyperemia or Color Reaction.**—The first is the hyperemia reaction, or living color test, suggested by Moszkowicz's‡ (Vienna, 1907) method of determining (preparatory to amputation) the limits of the living tissues in actual or threatened gangrene of the extremities, caused by arterial disease or obstruction. While the purpose and technic of Moszkowicz's and my own procedures are entirely different, they are similar in utilizing the hyperemic blush that follows an artificial ischemia in determining the limits of an adequate circulation. This test is reserved for the extremities, and is applicable to the limbs

* *The Sign of Pierre Delbet.*—The formation of an aneurysm or a tumor in the course of the main artery of a limb is often followed by the gradual or sudden obliteration of the peripheral pulses. (Posterior tibial, dorsalis pedis at the ankle, radial at the wrist, temporal and facial in carotid aneurysm.) When this occurs from any cause (mechanical compression, thrombosis, embolism or atheroma), without apparently affecting the nutrition or vitality of the extremity, it may be concluded that the collateral circulation has been fully established.

† The Bégouin and Moulinier's sign is based upon the development of pulsating vessels where normally these pulses do not exist. These new pulses on a level with or below the aneurysm or obstructive vascular lesion indicate that the collateral vessels have been developed; for instance, the superior articular arteries become perceptibly pulsatile in aneurysms of the popliteal, etc.

‡ Since the war Moszkowicz has contributed a valuable paper in which he utilizes the *hyperemic reaction* as a means of testing the efficiency of the collateral circulation. His technic is almost identical with my own. He does not appear to have been acquainted with the fact that I had anticipated him by about eleven years. While Moszkowicz was the first to utilize the hyperemic blush or color test for defining the safe limits of amputation in gangrene of the extremities, he does not appear to have utilized the hyperemia reaction in its applications to vascular wounds and aneurysms until the present war.

wherever it is possible to compress the main or parent artery of the limb, preferably with a mechanical compressor of the type of my own devising (Figs. 328–330) which exercises pressure on the main vessels with the least possible interference with the collateral circulation. The principle on which this test is applied is based on the fact that if the main artery is compressed in close proximity to the lesion (wound, aneurysm, tumor) sufficiently to arrest the peripheral pulses or "still" an aneurysm, the distal parts can be supplied with blood only through the collaterals. In order to make this test more effective and demonstrative, a complete ischemia of the limb is obtained before the compressor is tightened on the main artery by applying an elastic bandage (Esmarch) from the digits (and including these) to the level of the

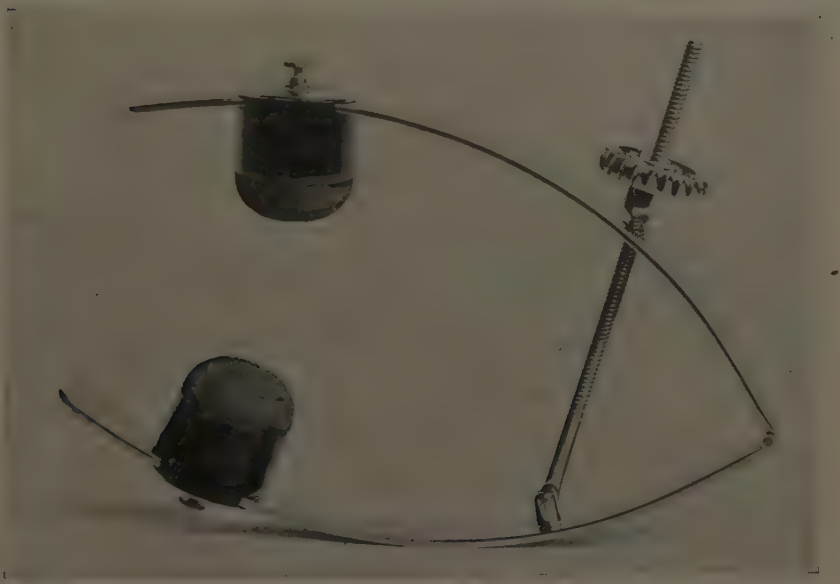

FIG. 328.—THE MATAS MECHANICAL COMPRESSOR FOR TESTING THE COLLATERAL CIRCULATION IN THE EXTREMITIES.

The main artery of the limb can be compressed without materially interfering with the circulation in collaterals.

lesion, usually an aneurysm. Then the compressor is adjusted until the aneurysm is absolutely stilled by firmly compressing the parent artery, and the elastic bandage is allowed to remain *in situ* for ten minutes in young subjects, and five or six minutes in the aged. The bandage is then removed while the main artery is completely occluded, as shown by the collapse and stillness of the aneurysm. Immediately on the removal of the bandage a hyperemic blush descends rapidly down the limb, and progresses onward to a variable extent, usually in proportion to the development of the collateral circulation. More often the hyperemic wave stops, even in healthy adults, at a distance of 5 or 6 inches from the compressor, or about one-fourth the distance down the limb from the level of the compressor. It then continues,

in a subdued color and with irregular distribution, to travel toward the periphery; but the extreme end of the limb, foot or hand, and especially the digits, retain a cadaveric, waxy, lifeless pallor for several seconds, which may be prolonged to ten or forty minutes or even longer, according to the development of the collaterals. Then the waxy, bloodless color changes in patches to a pale, but living color, which appears in various preferred areas, and gradually spreads uniformly and more or less intensely over the limb.

In cases in which the collateral circulation is unusually developed the hyperemic wave spreads in a few seconds throughout the whole limb, as if the main artery had never been compressed. If the com-

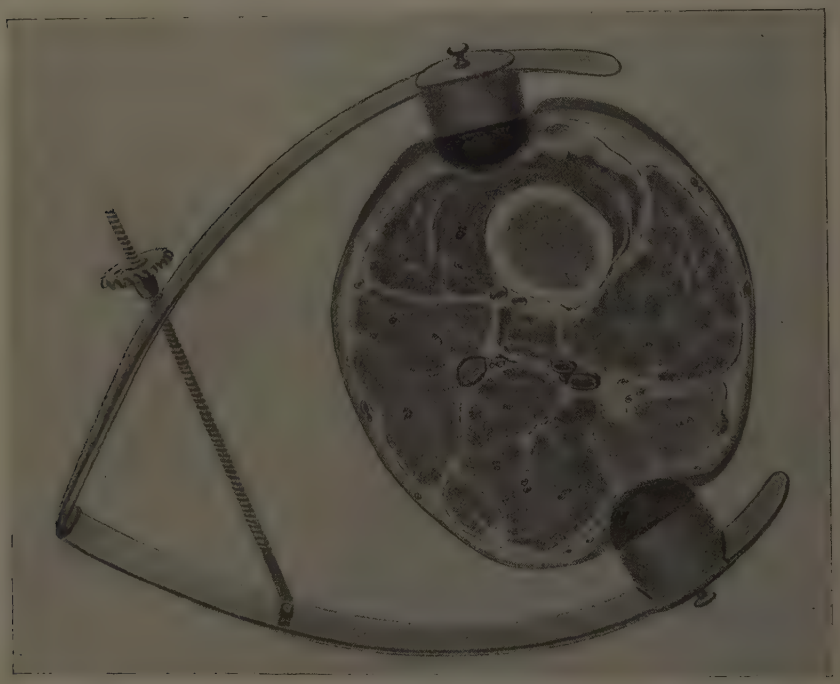

FIG. 329.—TRANSVERSE SECTION OF THE THIGH AT HUNTER'S CANAL.
The semi-elastic (rubber tipped) knobs jam the femoral vessels against the bone.

pression is kept up long enough there may be a temporary congestion, mottling and marbling of the skin, which is due to the simultaneous compression of the main vein. This is an additional sign that an efficient collateral circulation exists, as the veins could not become turgid without blood supplied by the collaterals. Thus far we have applied this test to over 59 cases of aneurysm and other lesions in our clinics, exclusive of those observed by other surgeons in the United States and abroad, and the conclusions furnished by this test have been invariably confirmed by the operative demonstrations and results. In several of these cases the reaction has been so long delayed that operative interference has been postponed for days and weeks in order

to develop the collateral circulation by systematic compression of the main artery with a mechanical compressor daily or twice daily. In addition, as an exercise in vascular gymnastics, the ischemia of the limb, from the extreme periphery to the trunk, should be obtained simultaneously with this compression by the Esmarch bandage, which should be retained in place for about ten minutes at a time and then released, watching the progress of the hyperemic blush and noting whether this reaction improves in intensity with the progress of the exercises. Dry hot-air baths and vigorous massage of the extremities, as well as other constitutional measures, such as a generous diet and forced ingestion of fluids, calculated to increase the blood-pressure, may be applied conjointly. In this way a decided shortening in the period of cadaveric pallor during compression of the main artery has been obtained, sufficient at least to justify confidence in the efficiency of the circulation and in the safety of the operation.

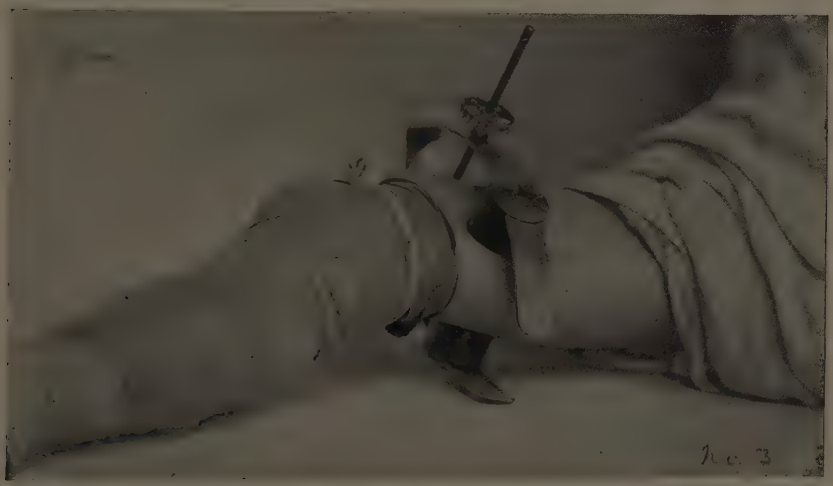

FIG. 330.—THE COMPRESSOR APPLIED TO THE FEMORAL ARTERY AT HUNTER'S CANAL IN TESTING THE COLLATERAL CIRCULATION IN POPLITEAL ANEURYSM.

(*b*) **Aluminum Band Test.**—The second test is based upon the preliminary occlusion of the main artery with the flat and pliable aluminum bands first described in 1911 in a joint communication by Dr. C. W. Allen and myself.* It is applicable to all arteries of the neck and trunk which cannot be effectively occluded by mechanical compression. In addition to my personal cases and with the valued

* As stated in Vol. V, Chapter LXX, the application of the flat aluminum band, here described, originated in the suggestion and researches of Prof. Wm. Halsted, of Baltimore (1906), whose experimental and clinical studies in the partial and complete occlusion of the great arteries with aluminum band mark a distinct epoch in the history of vascular surgery. But whether the bands be rolled around the artery with the ingenious instrument that he has devised, or applied as a flat band, as we (Matas-Allen) have found easier and more advantageous, there can be no question that the occluslon of the large surgical arteries, with the possible exception of the aorta, is much superior by these bands to any of the methods of occlusion for the preliminary testing of the collateral circulation thus far described.

collaboration of Dr. C. W. Allen and other members of our staff (Drs. Gessner, Maes, Cohn, and L. Landry) we have applied these in our clinics to all the great arteries of the neck and to the iliacs. At present we advocate the preliminary application of these bands in all cases of aneurysms or tumors involving the innominate, carotid, subclavian, and iliac arteries. If after total occlusion of the artery the peripheral circulation remains good, nothing further is done, and often the aneurysm is cured by this simple method. The band then remains permanently encysted in the tissues as a ligature. If there are evidences of a defective circulation which makes permanent cerebral disturbances probable when the common or internal carotid is involved, or when in the limbs permanent ischemia and gangrene are threatened (especially in the lower extremities), the band is relaxed just sufficiently to restore a living color to the periphery, the vessel remaining then only *partly* occluded. This procedure will diminish the activity of the circulation in the aneurysm and by gradual obliteration often lead to its cure, as originally and very clearly demonstrated by Halsted.

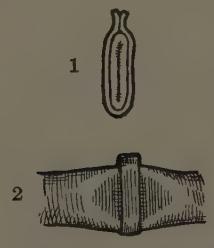

FIG. 331.—THE FLAT ALUMINUM BAND (MATAS-ALLEN).

1, Cross-section of the artery with the band applied to occlude its lumen without crushing the intima; 2, lateral view of the artery with the same band applied.

Technic.—The bands are cut long enough to be used as an aneurysmal needle; they are pliable and easily bent and curved in the shape of a flat hook, which can be readily insinuated between the blood-vessel and its sheath or, in some cases, over it. After the band has been carried around the circumference of the vessel, it is generally compressed by the fingers of the operator until the pulse on the distal side becomes imperceptible. The excess of the band which remains is cut off with stout scissors or, preferably, with small wire clippers. The bands should be perfectly smooth, polished and rounded at the edges, ready for immediate use after sterilization.

These aluminum bands as supplied by our local manufacturers* are of standard length (6 inches) and of the same thickness (23 Brown & Sharp's metal gage). In width there are three sizes: $\frac{5}{16}$ inch (approximately 8 mm.); $\frac{1}{4}$ inch (about 6 mm.); $\frac{3}{16}$ inch (about $4\frac{1}{2}$ mm.). In practice I have found that the $\frac{5}{16}$-inch band, 23 Brown & Sharp's gage (approximately $\frac{1}{2}$ mm., or exactly 0.573 mm.) is most generally applicable (Fig. 331). This approximates closely the width and thickness of the normal superficial femoral at its origin, and of the common carotid as measured by Ballance & Edmunds (loc cit.).

THE PACHON SPHYGMOMETRIC OSCILLOMETER† (Fig. 332)

"The main features in the construction of Pachon's instrument, which he names a 'sphygmometric oscillometer,' can best be understood by reference to the figure. The position of the aneroid *a* in the interior of the box, and the free communication of the interior of the same manometer with the box and the cuff, have solved the problem of devising an instrument which would have both a great and a constant sensibility at any pressure level. By reason of this arrangement the same pressure is exerted at all times on the external as on the internal surfaces of the drum *a*;

* McDermott Surgical Instrument Company, 734–738 Poydras Street, New Orleans, La.

† Norris, Blood Pressure, 1916, 2d ed., p. 110.

hence this drum is always in a position of rest or zero tension, except when by compressing *C* the cuff is placed in direct communication with the interior of the drum, and any change of pressure within the cuff may then act upon it. These changes of pressure due to the pulsations of the artery are normally very slight, so that the drum *a* would be made of relatively thin metal, and hence very sensitive. This sensibility will always be the same, no matter what the level of the pressure around the arm may be, since it always takes up the pressure changes in the cuff by starting from a state of no tension.

"In using the instrument the cuff is placed around the arm in the usual manner. Air is pumped into the system until the pressure is well above the normal arterial

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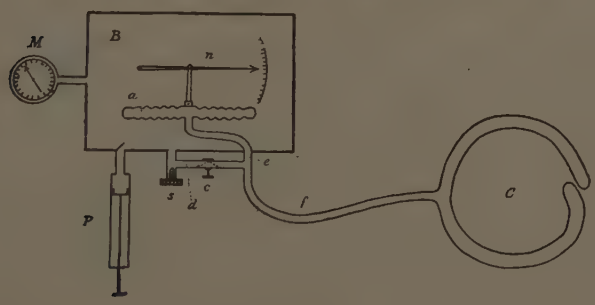

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FIG. 332.—1, THE PACHON SPHYGMOMETRIC OSCILLOMETER (Norris, "Blood-pressure"). 2, DIAGRAM SHOWING THE RELATION OF THE ESSENTIAL PARTS OF PACHON'S-SPHYGMOMETRIC OSCILLOMETER. (After Pachon.)

B is a rigid metallic box hermetically sealed and containing in its interior an aneroid drum (*a*) with which is connected the lever *n*. *M* is an aneroid manometer which indicates the level of the pressure in the entire system. The box, manometer, aneroid drum *a*, and the cuff are normally in free communication by means of the tubes *d*, *e*, *f*. The pressure can be raised in the system by means of the pump *P*; it can be lowered by allowing the air to escape by unscrewing the valve *s*. The cuff and the aneroid *a* can be cut off from the rest of the apparatus by compressing the rubber tube *d* by means of the compressor *c* (called separator by Pachon). (Bachmann.)

pressure. The amount of the pressure is read from manometer *M*. The observer now confines hisattent ion to the manipulation of valve *s* and compressor *c*, using preferably one hand only in order to insure free opening of the tube *d* when valve *s* is opened and closed. If on compressing *c* the hand *n* does not oscillate, valve *s* is opened and the pressure allowed to fall ½ to 1 cm.; *c* is again pressed upon and the hand *n* observed. This maneuver is repeated until oscillations of the hand *n* to the extent of, say, one degree of the dial are shown. This moment indicates the return of the pulse *at the point compressed*, and therefore the maximum or systolic pressure there. This is read on manometer *M*. To determine the minimum or diastolic pressure the pressure in the system is lowered in the manner explained above, and the compressor *c* manipulated between each lowering of pressure; at the

same time the hand, *n*, is observed, and at the moment its excursions are greatest the level of diastolic pressure has been reached, and can be read on manometer *M*. This is the most satisfactory instrument I have seen for the determination of the diastolic pressure; the oscillations are large, and the moment of greatest amplitude is clear cut, for both immediately before and immediately after this moment the oscillations are noticeably smaller."

The instrument is manufactured by C. Verdin, Rue Linne, Paris, and may be procured in this country from A. K. Thomas, Philadelphia, Pa., agents.

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Note.—All the references given in the text will be found in the following personal contributions, which have appeared since the publication of Volume V, 1909.

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Matas, R.: The Suture as Applied to the Surgical Cure of Aneurysm, Trans. Seventeenth Internat. Cong., London, Aug., 1913, report, Section of Surgery.

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Matas, R.: Testing the Efficiency of the Collateral Circulation as a Preliminary to the Occlusion of the Great Surgical Arteries; Further Observations, with Special Reference to the Author's Methods, including a Review of Other Tests thus far Suggested, Jour. Amer. Med. Assoc., Oct. 24, 1914.

SURGICAL TREATMENT OF WAR ANEURYSMS; ARTERIAL HEMATOMATA AND ANEURYSMAL SACS; ARTERIOVENOUS ANEURYSMS

A survey of the activities of the various surgical theaters of the war from the viewpoint of vascular surgery offers many contrasts as well as innovations in the mode of dealing with the war wounds of the blood-vessels, but none more striking than the different ways in which the arterial and arteriovenous aneurysms have been treated by the various belligerents.

The great frequency of aneurysm as a sequel to the gunshot injuries of the blood-vessels has been sufficiently referred to as a conspicuous feature of the war to account for the great interest centered upon them. I have already referred to the treatment of primary wounds, and have found that in dealing with these in the great emergencies of the battle-front there is a substantial agreement (with some reservations), and that the ligature still holds the supremacy as the simplest, quickest, and surest way to control a bleeding vessel. The dangers of the ligature as applied under the unfavorable surroundings and generally depressed circulatory conditions in which it becomes necessary at the first-aid stations and field hospitals, are recognized though not equally appreciated by all the belligerents. However, all agree that, under these circumstances, the risks of consecutive gangrene and nutritional disturbances of the brain after carotid injuries are practically unavoidable and must be regarded as one of the penalties of war. The great frequency of gangrene of the extremities at the front after ligation has been well brought out by Makins. His emphatic advice to delay all operations, whenever this is possible, shows an appreciation

of the great danger of the ligature, and the advisability of avoiding all interventions on the shocked and exsanguinated soldiers at the front unless they are absolutely necessary to preserve life. I have also noted that with the general adoption of the technic of prophylactic wound excision, which became universal among the Allies in the last two years of the war, the immediate or prompt treatment of the wounded blood-vessel exposed in the course of the débridement has brought out some contradictory statements in regard to the necrogenic influence of the ligature. The experience of the French operators would seem to show that primary ligature at the front is not so serious as the earlier statistics, especially the British and early German, would show. But the concession made by Sencert in favor of the lateral suture, whenever this is practicable in the course of the débridement, and the introduction of intubation by Tuffier, as a substitute for circular suture, and also the revival of the practice of simultaneous ligature of the satellite vein in arterial injuries, by Makins, show plainly that the Allied surgeons recognize that the ligature under these difficult conditions is a procedure of necessity rather than of election. The disasters of the primary ligature of the large vessels at the front on the German side, illustrated by the oft-quoted experience of Hotz, who had 5 cases of hemiplegia after six ligatures of the carotid and 4 cases of gangrene after six ligatures of the femoral and popliteal, have led several German surgeons to advocate the suture as a substitute for the ligature in field hospitals, but this practice has found few adherents even among their most enthusiastic suturists. Okinczyc, whose experience with the French Army at the front contradicts some of the statements made as to the relative benignity of the ligature at the front, regards it simply as a procedure of necessity, and should be put off if at all possible to do so. But the prophylaxis of wound infection is paramount to all other considerations, and wounded vessels, whether bleeding or not, when exposed in the course of this procedure, must be disposed of in the most expeditious way possible. He believes that when the patients survive the primary effect of their injuries this prophylactic wound cleansing will save them from the dangers of secondary hemorrhages and secondary aneurysms. By this practice the future or remote dangers of vascular wounds will be avoided, but the liability to gangrene in shocked and exsanguinated patients will remain as great a danger as in the past.

Traumatic Arterial Hematomata.—Once the hemorrhage into the tissues is arrested spontaneously, or is limited and confined to distinct perivascular areas, which are in communication with a wounded artery, a hematoma is established. The vascular lesion may be either arterial or arteriovenous, and if there is no infection, no secondary hemorrhage, no urgent pressure signs, or sudden increase in the extravasation, which is true of the vast majority of these circumscribed hematomata, the indication for an immediate intervention ceases. Here, again, we find some difference of opinion. Some German and French surgeons would operate promptly upon all the hematomata whether limited or diffuse, taking no chances with the possible infection, and as

a prophylactic measure against future complications. But the opinion expressed by Makins, we believe, is in harmony with the opinions of the majority of all the belligerent surgeons: "When evidence exists that a large vessel has been wounded in the course of a track traversing the body or limbs, unless the conditions are favorable, it is not advisable to interfere primarily, if no signs of progressive hemorrhage exist, nor indications that the vitality of a distal portion of the limb is becoming endangered. In all such cases, although an arterial hematoma, and subsequently a false traumatic aneurysm may result, yet the later treatment of either of these conditions, under favorable circumstances for operation, is to be preferred to the risks attendant upon a primary operation." If this view is accepted, the patient is evacuated or transferred from the front to the base or home hospital, and if no accidents (infection, hemorrhage, etc.) occur in transit, the wounded man has time to recover from the immediate effects of shock, surgical anemia, exhaustion, etc. Here, under the influence of rest, both general and local, his nutrition is improved, his cardiovascular mechanism is given an opportunity to assert itself, to display its resources in establishing the collateral circulation. The local tissue defences are also started, the elimination of any relics of infection is assured, and the hematoma is reduced to a well-walled pool of circulating blood. The vitality of the dependent parts by the progressive development of the supplementary routes of the circulation is also assured.

It is when the patient has reached this stage of comparative safety that we notice the greatest contrast in the attitude of the different surgeons in the belligerent camps. All agree that with the exception of some arteriovenous lesions (simple arteriovenous fistulæ) the aneurysmal tumor must ultimately be subjected to operation.

When to Operate.—But *when* and *how* is the question upon which the different groups of surgeons disagree. Nearly all are in accord that the patient should be given time to recover from the immediate and depressing effects of the primary injury. Makins has emphasized the British viewpoint in favor of expectancy for as long as two and three months after the injury, and so has the Allied Surgical Conference (Paris, 1917) favored delay. All intervention should be put off long enough not only to improve the general condition, but to develop the resources of the collateral circulation, and to assure the asepticity of the wound. In this way the operation is usually put off until the aneurysmal sac has formed—four to six weeks.

The Germans, at least some of the most representative among them, advise early operation regardless of the collaterals, though they recognize that this collateral circulation is established with remarkable rapidity once the general condition has improved. Influenced by their confidence in the methods of suture, as a means of restoring the continuity of the injured blood-vessel, they claim that the right time to operate is in the early hematoma stage, before the pseudo-aneurysmal sac has had time to form, and just as soon as the sterility of the wound is practically assured. Some, however, do not even wait for this to occur,

and have operated even in the presence of very serious infection. If the operation is performed before the sac has had time to develop the naked blood-vessels are more easily exposed, dissected, and mobilized, and in this way are more amenable to suture than when they become encased in the sac or in dense cicatricial tissues.

It is notable, however, that whatever their confidence in the ability to restore the continuity of the vessel by suture, they are most cautious in the preservation of all the collateral branches.

However, there is far from unanimity among the German surgeons on this point. Probably the majority prefer to wait for the wound to heal and the collaterals to develop. Some fix a time limit for the operation. In Bier's 102 cases the operations were performed within an interval of from 8 to 105 days. Usually three to five weeks is given as the approximate time, while others prefer a much longer period. A tendency to prolonged delay is observed in attacking the most dangerous aneurysms at the root of the neck and groin, where, unless urgent pressure-symptoms occur, the surgeon will keep hands off as long as possible.

Evidently this is not a problem that can be settled by the calendar. Apart from sudden emergencies, which may alter any predetermined plan at any time, there can be no definite time to operate. This must be determined by the general and local conditions in each individual case, and, in fact, should not be determined by any arbitrary rule. The surgeon who, without any special urgency in the symptoms or signs, would operate early, in the hematoma stage, merely to facilitate a suture, disregarding other conditions, will do so at the peril of life and limb, or of other dependent parts (the brain in carotid injuries). Those who would operate under the safest condition will not consult the calendar, but will look for nature's signs of preparedness. They will be guided by the condition of the cardiovascular mechanism and by the frequent study of the behavior of the peripheral circulation when the involved trunk is temporarily occluded. When the tests previously described show that the collateral circulation is efficient and dependable, then, if there are no other contraindications, that *is* the right time to operate. It should be remembered that no matter what may be the conservative procedure adopted, there is no method that will guarantee that the vessel will remain pervious. The most skilled surgeon must reckon with this possibility. While the probabilities of success or failure to preserve the physiologic continuity of the blood-vessels are undoubtedly very much influenced by the technic adopted, the method of its performance, as well as the conditions under which it is performed, the statistics of the suture all show a very considerable percentage of gangrenes which demonstrates that the best arteriorrhaphy is no proof against this disaster. Therefore, in all these cases in which time is given to choose the opportunity for the operation, the surgeon will serve the best interests of the patient if he will familiarize himself with the behavior of the peripheral circulation after the temporary occlusion of the main artery. This is particularly true of the circumscribed

and mature hematomas of the neck in the carotid tracts, also those of the groin and of the popliteal region in which the danger of peripheral anemia is greatest. It is to be regretted that the methods of testing the circulation in a preliminary way, which were available long before the war, have not been utilized more often at the base hospitals, and that, in consequence, the suture and the ligature have been applied indiscriminately and too often as routine measures. It is easy for those who have not made it a practice to study the behavior of the peripheral circulation with the various methods of preliminary occlusion to discount their value or minimize their importance. A long experience has taught me that the operator who prepares himself by a careful study of the circulatory reactions of his patients under various test conditions, has a decided advantage at the operating table, and is much less liable to painful and disappointing postoperative surprises.

The Methods of Ligation.—All the surgeons in this war, both Allied and German, agree, theoretically at least, that the restoration or preservation of the continuity of the wounded vessel is the ideal to be aimed at, and that this is best accomplished by either the lateral or circular suture. The Allied surgeons, British and French especially, differ from the German in that they have found comparatively few cases in which the suture, and especially circular arteriorrhaphy, is applicable. They claim that the condition of the wounded vessels and of the perivascular tissues, as revealed at the operation, are such as to preclude the successful application of the suture in the vast majority of the wounded. They contend that, at this stage, when the hematoma is well circumscribed, or an aneurysmal sac has developed and the patient has recovered sufficiently to bear transportation to the base hospitals, the collateral circulation has been established, and that an arteriorrhaphy is unnecessary. Apart from the fallacies that underlie the suture methods, the immediate and remote results of the ligature are just as satisfactory as those of an arteriorrhaphy, and for these reasons they almost invariably apply it to all traumatic aneurysms as well as to hematomas.

"With M. Quenu, Walther, L. and R. Picqué, Bazy, Monod, Mauclaire, Faure, Fredet, and so many others who have reported to this Society a number of traumatic aneurysms cured by ligature, I esteem it that the suture of the arteries in these cases has no place in army surgery. The simple ligature placed on healthy vessels gives satisfactory results, and has the advantage that it is within the reach of every one, at all times and in all places. The functional prognosis is absolutely benign, if we must judge by the published reports. The future usefulness of the soldier, his rehabilitation to service, is in no way compromised," etc. (H. Toussaint).

The ligature has been applied to wounded blood-vessels in this war in all its forms or modalities: single, proximal, next to the lesion (Anel); at a distance (Hunter); distally (Brasdor, Wardrop), and on each side of the wound, with or without division of the artery, and by the quadruple method in arteriovenous lesions or aneurysms, with and without the excision of the sac. The Hunterian proximal ligation in continuity has been almost discarded except in certain regions (internal iliac, subclavian, and carotid tracts) where it still yields excellent results in dealing with pure arterial aneurysms, especially when an ad-

justable aluminum band is substituted for the ligature, in the manner I have described in other sections of this chapter. In a general way the ligature in the wound, in a healthy segment of the artery, and as near the lesion as possible, so as to exclude as short a segment of the vessel as possible—in accordance with the old but sound teachings of Guthrie, Dupuytren, and Bell—has been almost universally applied in these war traumas and hematomas. A certain number of operators, however, have resorted to the intrasaccular ligature which, on account of its special advantages in war surgery, deserves special consideration.

The Intrasaccular Ligature.—It is remarkable that this, in many ways, excellent method of dealing with aneurysmal sacs which had its origin on Scottish soil, and found in Syme, and especially Annandale, its highest exponents, should have been practically forgotten in British practice until it was revived by the Japanese. This method, which was also practised by several of the Russian surgeons, came to the present war as a legacy from the Balkan campaigns where it was popularized by Frisch, of Vienna,* by whose name it is often designated in the German literature. Many surgeons working with the various Balkan Armies express themselves favorably in regard to it. At the present time among others, Ranzi (1918), speaking from Eiselsberg's Clinic, believes that it is the safest of all the ligature methods. Among the Germans the methods of suture, however, have largely displaced it in the present war. The French surgeons, who almost invariably extirpate the sac, never mention it in any of their writings. Makins wrote favorably of the method at the beginning of the war, but scarcely mentions it in his last monograph of 1919. McAdam Eccles refers to it also, but he applies it in such a modified way that it can scarcely be recognized as an intrasaccular ligation. Of all the British surgeons, Pearson has expressed himself most forcibly and convincingly in favor of the intrasaccular method in arteriovenous as well as arterial aneurysm, and in reporting his excellent results lays stress upon the advantages of the intrasaccular route, doing an intrasaccular ligation whenever the restorative intrasaccular suture is not practicable (Fig. 333).

I described this method in 1909 (Vol. V, p. 268 *et seq.*), and there is little to add to that description except that while recognizing that it is superior to all the methods of ligature in sacless or immature hematomas,

* The term "intrasaccular ligature" implies that the ligature is applied through the walls of a fully formed aneurysmal sac (in reality, a transsaccular ligature of the parent vessel), and it is in this sense that the term was applied by Syme and Annandale (Fig. 88, p. 281, Vol. V). But Kikuzi and the Japanese surgeon who described this procedure as the "intracapsular ligature," and von Frisch and the German surgeons who followed him in the Balkans, resorted to the ligature in circumscribed hematomas in which there is no formed or organized membranous sac, but merely a well walled cavity filled with clot in which the wounded vessels lie more or less exposed and can be ligated or sutured directly, as in an open wound (Fig. 101, p. 305, Vol. V).

In comparing the intrasaccular ligature and the intrasaccular *suture* I have in mind the original description of the intrasaccular ligature in an aneurysmal sac as understood by the Scottish surgeons, and not the extension of this term to the hematomas, as is done by the Japanese and the Balkan surgeons. The difference between the two technics (intrahematomatous and intrasaccular) are too obvious to be insisted upon.

and can be applied equally well to arterial and arteriovenous lesions, it is inferior to the obliterative endo-aneurysmal *suture* when the sac has formed. The chief objection lies in the fact that when the collaterals open into the sac, which is quite frequently the case, these vessels cannot be controlled by the ligature inside of the sac, and this has to be

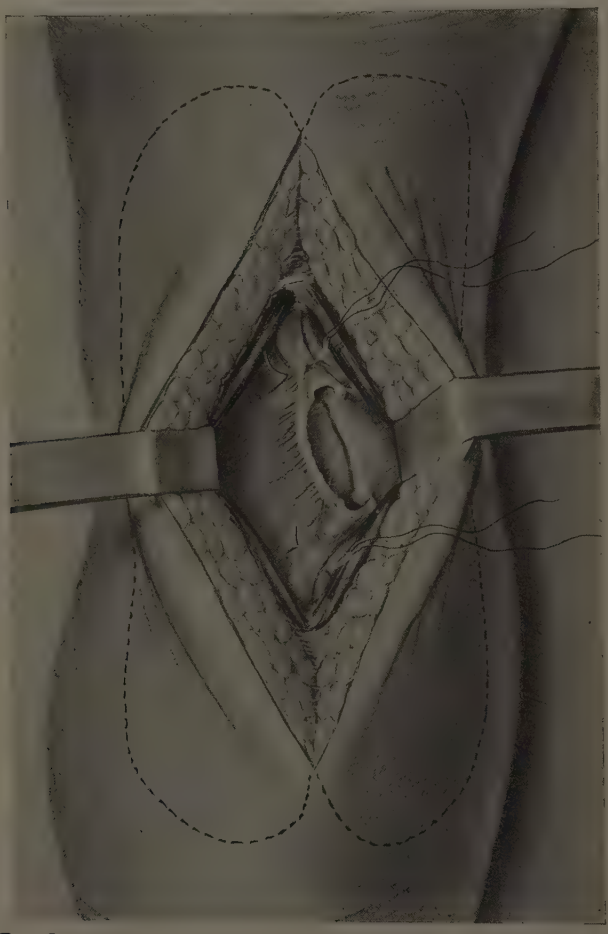

FIG. 333.—THE INTRASACCULAR *Suture Ligature* APPLIED TO A *Ruptured Popliteal Aneurysm* (PATHOLOGIC).

The dotted lines show the area of extravasation filled with clot. The popliteal artery was so badly damaged that a conservative suture was impracticable and the torn ends were ligated without dissection by obliterating them with encircling sutures. The collateral circulation was demonstrated efficient by previous tests. (Original drawing from sketches at operation. Case of Richard P., Charity Hospital. Operated by Dr. Matas, November 19, 1917; complete recovery.)

dissected out to reach them. In this way the chief purpose of the intrasaccular method, which is to disturb the sac and the perivascular tissues as little as possible, is lost. This the endo-aneurysmal method of suture usually accomplishes with the greatest ease and certainty by sealing every one of the orifices that open into the sac by the suture applied entirely within the sac. Some surgeons have suggested and

practised the intrasaccular ligature combined with obliteration of the sac by suture and plication. In this way they have endeavored to overcome the chief objection to the intrasaccular ligature; but this hybrid mixture of the ligature and the suture is an unnecessary complication. It is contrary to the principles of the intrasaccular suture (endo-aneurysmorrhaphy) which resorts to plication as a supplementary procedure, solely to obliterate the collapsed sac, but not for hemostatic purposes. Plication should only follow after the suture of the individual orifices opening into the sac has been accomplished.

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THE METHODS OF SUTURE AS APPLIED DIRECTLY TO THE BLOOD-VESSELS: ANGIORRHAPHY (LATERAL, CIRCULAR) IN SACLESS HEMATOMA

In the World War the suture of the blood-vessels as a conservative measure has been applied more often and more systematically than at any other time in the history of surgery. It has been applied in all its forms and in all its phases, directly to the wounded blood-vessels and to aneurysmal sacs.

Long before the end of 1917 German surgical literature showed that fully 1000 and more war aneurysms had been treated by the methods of suture, thus seemingly confirming the opinion that the suture was applicable to many, if not the majority, of war hematomas and aneurysms. Therefore from the German viewpoint the suture is not only theoretically but also practically the method of election in the treatment of vascular lesions, and the ligature is to be regarded only as a method of necessity. Complete statistics assessing the relative value of the suture and the ligature cannot be available for a long time; hence, meantime, valuable comparative experiences of individual, well-known surgeons must be utilized. The following titles will furnish the reader with these references:

Bier (Bruns' Beitr. Krieg's Chir. Hefte, 1915, Bd. 556); Küttner (Berlin, klin. Woch., 1916, No. 6); Ranzi (v. Eiselsberg's Clinic; Archiv. f. Klin. Chirurg., Bd. 110, 1918); Zahradnicky (Wien. Klin. Woch., Aug. 4, 1915); v. Haberer (Münch. med. Woch., vol. 65, 1918, p. 363); Soubbotich (Bull. et Mem. Soc. de Chirurg., Part I, 42, No. 7, 1916).

Salomon (Beiträg. z. Klin. Chirurg., Bd. 112, 1918), in his analysis of 490 vascular injuries treated at Rehn's clinic, Frankfort, reports that **suture methods** were applied in 185 cases with 78.3 per cent. cures (74.5 per cent. were positive cures and 3.8 per cent. improvements); 21.7 per cent. failures (including 7.8 per cent. gangrenes and 9 per cent. deaths). Of this number, *lateral sutures* were applied in 94 cases, or 50.8 per cent.; *circular*, in 73 (39.1 per cent.). With venous transplants, 18 cases (9.7 per cent.). The 94 lateral sutures were followed by gangrene and amputation in 8 (8.4 per cent.) and failure to cure in 4, that is, 12 failures (12.7 per cent.); 9 deaths (7.6 per cent.) and 73 successes. The 73 circular sutures were fol-

lowed by 7 failures (9.5 per cent.), including 2 amputations for gangrene and 7 deaths (9.5 per cent. mortality). The 18 interposed venous grafts were followed by 1 death and 4 gangrenes (22.2 per cent. gangrenes).

The Suture Applied to Aneurysmal Sacs, with Commentaries on the Methods of Suture by the Leading German Operators During the War.—In the application of the methods of suture as practised by the German surgeons during this war the distinction between the immature, recent hematomas (sacless) and the aneurysms (sacculated) must be kept in mind. In dealing with the sacless hematomas they have performed direct, simple angiorrhaphies, arterial or venous, or both, as in the operation for arteriovenous lesions. In operating upon aneurysmal sacs they have practically abandoned the so-called "ideal operation" of Lexer, in which the sac is extirpated and the divided vessels are united by an end-to-end or circular suture.

The Treatment of the Sac.—The above-mentioned surgeons and their followers, who are leaders in this work, no longer extirpate the sac, but close the orifices leading to the parent artery by an intrasaccular suture, and in this way do an endo-aneurysmorrhaphy of the restorative type, as advocated by Matas. When the artery has been completely divided, or so badly injured that it is impossible to close the orifice of communication without obliterating the lumen of the vessel, they prefer to dissect the vessel out of its bed through the wall of the sac, and after freeing it from its connections, mobilize it sufficiently to do a circular suture within the sac [transsaccular arteriorrhaphy—R. M.]. As a glance at the statistics will show, the lateral suture within the sac is applicable to at least one-half the cases (58.8 per cent.—Salomon; 51.3 per cent.—Bier; 60 per cent.—Zahradnicky). Judging by this fact, the German operators, who have followed the lead of Bier and Kuttner, have virtually performed my restorative operation in about 50 per cent. of their sacculated cases.

The respect for the aneurysmal sac and the appreciation shown by the German operators for its protective value, and plastic qualities, is one of the interesting developments of the war. Says Bier: "Sac extirpation, formerly a customary procedure, is a mistake, because by this method too much of the artery is sacrificed, and with it the most important collateral branches." Again: "When the *ligature* is applied (by the intrasaccular route) at least the sac should *not* be extirpated, as there is no sense in so doing, besides complicating one of the simplest of the efficient obliterative methods."

Küttner not only believes that the sac should not be disturbed from its surroundings, but that in dealing with comparatively small perforations in large arteries the closure of the opening is much facilitated by passing the suture through the thickened, callous margins, lined with endothelium, which form a collar around the orifice, even in immature or partially formed sacs. In this he also does what I have practised and advocated long before the war. It is also quite significant to read that: "It is an unconditional rule that the total extirpation of the entire sac—with all the collaterals contained in it and with

the entire segment of the main vessels passing into the sac wall—*should be avoided*" (Küttner, Berliner klin. Woch., No. 6, 1916).

Aneurysmoplastics.—Küttner has gone much further than other operators in utilizing attached flaps of sac to cover or patch up extensive defects in the arterial wall. Basing himself upon the histologic studies of Justi, of the Breslau Institute, who found that the pseudosac in traumatic aneurysms is not only well lined with endothelium, but is well provided with elastic fibers which have been reproduced from the media, Küttner has performed 4 aneurysmoplasties in which broad pediculated flaps cut out of the sac are utilized very effectively, with seemingly good permanent results (Fig. 334). In this way he has avoided circular arteriorrhaphies, which are especially undesirable in the neighborhood of joints. It is quite evident that if so experienced a surgeon as

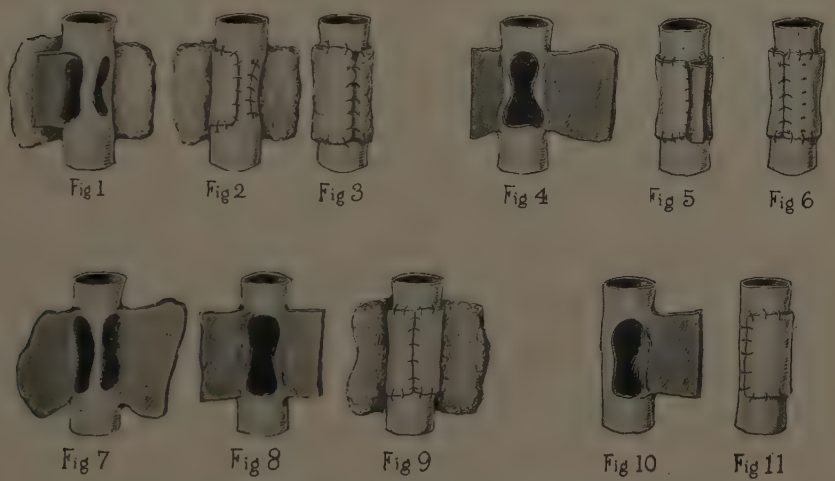


FIG. 334.—*Vascular Plastics; Aneurysmoplastics:* SHOWING THE METHODS ADOPTED BY H. KÜTTNER TO PATCH DEFECTS IN THE PARENT ARTERY CAUSED BY GUNSHOT INJURIES.

Strips or attached flaps cut out of the aneurysmal sac are sutured over the defects and are reinforced by similar pads of periarterial fat or fascia. (From Küttner, H., Gefassplastiken, Münch. Med. Woch., 1916, lxiii, 721–723.)

Küttner would prefer to patch a badly injured artery with sac flaps rather than do a circular arteriorrhaphy, we should regard a reconstructive endo-aneurysmorrhaphy as equally safe, if not more advantageous, than a circular arteriorrhaphy in cases in which the former procedure is applicable. Advocating the preservation of the lumen by a restorative and reconstructive intrasaccular operation I have, however, never favored the use of sac flaps for patching arterial lesions in aneurysmal sacs. It would appear to me that the dissection and detachment of such flaps from their surroundings, even when broadly pediculated, would impair their vascularity and nutrition so that the endothelial lining would suffer degenerative changes that would predispose to thrombosis in the patched segment. The success which has attended Küttner's plastics, even though limited to 4 cases, shows, however, that,

even under these unfavorable conditions, the material furnished by the sac can be relied upon to restore the lost lumen of the vessel. If this is true of Küttner's plastics, how much more dependable are the restorative aneurysmorrhaphies in which the lumen of the artery is restored by simply suturing together the margins of the orifice communicating with the sac; or, in favorable cases, a missing segment of the vessel is reconstructed out of the uninjured, unimpaired, and undetached sac walls. I have laid down as a fundamental principle that the essential conditions for a successful restorative or reconstructive intrasaccular suture is that the sac, in the line of the continuity of the arteries, must remain undisturbed and intact in its perivascular surroundings. If the sac is detached or dissected out of its bed its nutrition will be impaired in a way that may lead to necrosis of the sac, or to such degenerative changes that a thrombus will follow.*

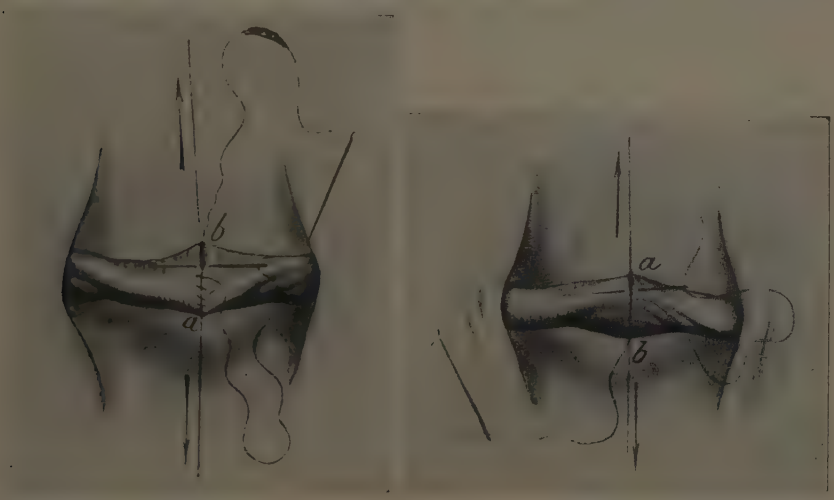
Intra-aneurysmal Obliteration of Vascular Terminals by Suture in Sac.—Another view brought out by Bier, which I have long held, is that the occlusion of the arterial terminals in a sac, or in the dense infiltrated tissues which form the bed or capsule of a mature hematoma, is preferably treated by suture than by ligature, because in this way absolutely no segment of the injured vessel is sacrificed, and no collaterals originating in close proximity to the arterial stump will be excluded. As the endothelial proliferation suffices to line the margins of the arterial wound at a very early stage of the hematoma with smooth, polished, and thickened contour, the suture of the terminal edges is much easier than in an ordinary arteriorrhaphy. In this way the open terminals of a vessel, as seen at the bottom of an aneurysmal sac or a hematoma, can be closed directly and very economically without the need of refreshing or resecting the edges. Even Makins, who seems to be constitutionally opposed to any sort of intrasaccular suture except in arteriovenous sacs, acknowledges that this obliterative application of the suture has real advantages.

TECHNIC OF VASCULAR SUTURE (ANGIORRHAPHY AND ANEURYSMORRHAPHY) AS MODIFIED BY THE EXPERIENCE OF THE LATE WAR

Much of the popularity of the suture among the German surgeons in the late war is no doubt due to the comparative simplicity of the technic which, following the lead of Bier and Küttner, they have generally adopted. The difficulties in the technic of suture as applied to adult human arteries has been no doubt much overrated. The suture of the large surgical arteries in which it is especially called for are all much larger and more resistant than those of the dog and other small laboratory animals, for which the fine needles and thread of Carrel are necessary. As suggested by Bier, the three supporting or guy sutures of Carrel or Guthrie, which transform the circular margins of the ap-

* Incidentally Eloesser has sought to patch defects in arteries by covering them with fat transplants, Kirschner and Neuhoff, of New York, with fascial transplants, but these are all free grafts in imitation of Carrel's experimental methods of patching with these and other tissues.

proximated vessels into triangular lines, are not necessary. Bier,* Küttner, and others have used only two guy sutures, which are passed through and through the edges of the approximated vessels at opposite points, either in the anteroposterior or lateral diameter of the vessel. The guy sutures are of the mattress or U type of Jaboulay and Briau, which on traction bring the edges to be approximated or sutured on two parallel lines instead of three, and suffice to keep the endothelial edges in confrontation. A running stitch with fine ophthalmic, paraffined silk, extending from one traction suture to the other, will bring the everted endothelial edges into perfect approximation. Short fine milliners' needles, or ophthalmic curved needles (Knoll), with a silk that will fit the eyes of the needles, so that the needle tracks in the tissues



a *b*

FIGS. 335, 336.—MOURE'S MODIFICATION OF THE CARREL TECHNIC OF CIRCULAR ARTERIORRHAPHY, APPLICABLE TO ARTERIOVENOUS ANASTOMOSES AS WELL.

Only two traction or guy sutures are inserted at equidistant points, instead of the three traction sutures of Carrel. A continued running silk stitch extending from one guy suture to the other is sufficient to bring the endothelial surfaces into accurate apposition. This simplified technic is well adapted to the larger human arteries. It was adopted early in the war by Bier, Küttner, and other German surgeons in their many arteriorrhaphies, without apparent knowledge of its French origin. *a*, First line of sutures; *b*, second line of sutures. (From P. Moure, "Les Greffes Artérielles," 1914.)

will be well filled by the thread, will in this way avoid leakage. The fine Kirby needles (Nos. 16 and 17), used by Carrel, or the curved needles of Jeger are only required for laboratory animal work. One assistant holds the traction sutures taut. No mention is made of any special appliances to hold the traction sutures.

Some surgeons prefer interrupted mattress sutures, or even a cobbler's stitch, but, in general, a plain, running stitch, continued from one of the guy sutures to the other is preferred. Apart from this modification and the good care to preserve the collateral branches, given off in close proximity to the line of suture, the technic of arteriorrhaphy is

* This simplified technic by which two instead of three traction sutures are used was described and illustrated by Paul Moure in 1914 (Les Greffes Vasculaires, Doin, Paris, 1914, p. 86).

that of Carrel, as described in Vol. V, p. 133. In this way circular arteriorrhaphy has been applied after resection of segments of 5 and 7 cm. Usually in these cases the limb has been kept in flexion and the head bent forward and laterally, in carotid sutures (Parazewski). W. Knoll advises that should extreme flexion be necessary for approximation, active and passive movements of the limbs may be begun at the end of fourteen days without endangering the suture line. This forced flexion, as Küttner has pointed out, has great disadvantages, not only in leaving the limb stiff and ankylosed and also in endangering the suture line by overstretching when the limb is extended, but also increases the risk of thrombosis and peripheral gangrene by the acute bending of the vessel.

In doing a *lateral* suture the wound or orifice in the vessel is closed by approximating the endothelial margins either in a longitudinal direction, parallel with the long axis of the artery, or transversely. Cases are reported by Bier and others in which the caliber was reduced to one-half or one-third of its normal diameter without serious impairment in the circulation.

Restoring the Continuity of a Divided Artery by Interposing a Venous Graft.—Much was expected of this method as a means of overcoming large arterial defects, but the results of this procedure tried on an extensive scale at the beginning of the war have been disappointing, and the majority of German surgeons have given it up, at least in war surgery. Following Lexer's precedent, the saphenous vein has been most frequently used as a graft, and a few have availed themselves of the associate or satellite vein. No other materials, such as arterial segments of autogenous or heterogenous or cadaveric vessels, have been used except, perhaps, in the isolated instance of Jeger, who successfully utilized venous and arterial grafts from limbs that had been shot away.* Since the aneurysmal sac is no longer extirpated, the endo-aneurysmal suture has been adopted by Bier, Küttner, and others, and there is scarcely any need of grafts. The chief objections to this operation is that the venous transplants become thrombotic or undergo atrophic and obliterative processes in the majority of the cases, and that the operation involves a much more complicating and dilatory technic, all of which is quite unsuitable to the conditions of military practice.

In connection with the technic of suture many of the German surgeons have supplemented the circular suture by enveloping the sutured vessel in a muscular or fascial flap, or with a piece of excised vein.

* In connection with the transplantation of blood-vessels immediately removed from amputated limbs, referred to by Küttner and others, as having been performed successfully by Jeger at Premzyl, the experiments of Nageotte and Sencert, in which they relate a successful experimental transplantation of animal and human tendons, nerves, and arteries, with dead grafts which had been preserved in alcohol for a month and which appear to have been grafted with permanent functional success, are worth noting as possibilities of surgical utility. These differ from the Carrel vascular grafts, which were intended to be kept alive in cold storage and embedded in vaselin.

This has been done to protect the sutured segments from infection and secondary hemorrhage.

Infection and the Suture.—Infection in a wound is regarded practically by all German surgeons as a contraindication to suture; nevertheless, a number of operators have sutured the blood-vessels in badly infected wounds with apparent success, at least in so far that no disastrous consequences followed. However, it is quite evident that infection, no matter in what shape, is almost certain, by either thrombosis or secondary hemorrhage, to vitiate the effects of the suture. In these wounds the ligature is always to be preferred. As a rule, in infected hematomas, if the intrasaccular suture is adopted at all, the cavity should be allowed to remain open or drained.

The Fallacies of Direct Arterial Suture (Arteriorrhaphy) with Special Reference to Circular Arteriorrhaphy.—These, as I have repeatedly pointed out before the war, are not all negatived by the undoubted surgical successes of the German operators. These fallacies are the liability to occlusive thrombosis in the line of suture which admittedly occurs in a very considerable number of the cases and in the absence of all infection, as a result solely of the trauma. This is the greatest objection, and then the possibility of secondary hemorrhage from infection, pan-arteritis, and third, the possibility of recurrence by yielding of the suture line. This last possibility is practically negligible, as it occurs very rarely.

In regard to thrombotic occlusion, the experimental evidence shows that even in the best conditions, in laboratory animals, the suture, and especially the circular suture, is liable to a very considerable percentage of failures through thrombotic occlusion or cicatricial stenosis. Even with the Carrel technic in skilled hands, according to Sofoteroff, thrombosis occurs in a large percentage. Clinically, in war wounds the probability of thrombotic occlusion is even greater. I collected from the literature before the war 49 circular sutures which had been performed in civilian hospitals and in peace conditions. A careful analysis of the available postoperative evidence showed that 13.1 per cent. had been followed by gangrene. Of the 37 patients who recovered, in no less than 33 (87.6 per cent.) by circular suture with and without interposed grafts, the anastomosis had proved functionally valueless or superfluous, if we are to judge by the behavior of the peripheral pulses.

The majority of the German surgeons seem to take it for granted that because the limb survives, escapes from gangrene, and because the functional results are good, that the anastomosis as such is a success, and no doubt it is as far as the cure of the lesion is concerned, but this does not prove that this success is due to the preservation of the continuity of the arterial lumen. The uncertainty of the ultimate fate of the sutured vessel is frankly admitted by Bier and most of the German surgeons, who contend that, even if the lumen at the suture line is ultimately obliterated in many cases, this occurs gradually, giving plenty of time for the establishment of an ample collateral circulation. Bier insists that in doing a circular suture the preservation of the collateral

branches is of the greatest importance. This great insistence on the preservation of the collaterals is the logical outcome of Bier's acknowledgment that, in spite of the best of sutures, the artery may become thrombotic. The statement of Bethe is significant. Bethe performed 6 circular sutures in 21 operations for aneurysm, but "only in one instance could the peripheral pulses be permanently demonstrated."

Graf confirms this view in reporting 8 arteriorrhaphies for traumatic aneurysms. Most of the sutured and ligated cases resulted in limbs that were normal in temperature, color, and sensation. None the less, the pulse after the operation could not be felt at the ankle in the femoropopliteal cases, but could be felt at the wrist in the brachial cases. These facts tend to prove Moszkowicz's contention that the undoubted success of the methods of arteriorrhaphy are not due so much to the restoration of the vessel lumen, but rather to the non-interference with the collateral circulation, the *gradual* occlusion of the sutured segment, and to the great care exercised in preserving the collaterals in the course of the operation.

In the end, therefore, in dealing with traumatic as well as pathologic aneurysms, the margin of safety lies in the integrity of the collateral circulation, and in this the writer is in thorough accord with Makins. This conclusion seems to be borne out by the generally satisfactory results claimed by all the belligerents in spite of their seemingly contradictory or opposed methods. The German surgeon claims that the conservative methods of suture are the safest and the best; the French are equally well satisfied with their method of ligation and extirpation of the sac; the British are also well pleased with the results of the ligature with or without extirpation, when this is done on each side and as close to the lesion as possible, and as long as the operations are delayed and performed at the base hospitals. It is to be noted, however, that both French and British surgeons have been leaning far more toward the methods of suture, whether intrasaccular (in arteriovenous aneurysms especially) or directly as arteriorrhaphies, than in the beginning of the war. All the belligerents are equally dissatisfied with the results obtained *at the front* where the ligature is admittedly the only treatment applicable to the great emergencies and conditions of the firing line, but they are all seemingly well pleased with the results of the various methods applied at the base.

Conclusions in Regard to the Conditions which are Common in the Treatment of War Aneurysms, and which Harmonize the Different Methods Adopted by the Different Surgeons in the Belligerent Armies.—How, then, are we to reconcile these apparently contradictory methods with the same, or nearly the same, results claimed by each of the belligerents? Evidently, there must be one or more factors that are common to all regardless of their discrepant technics. These common factors in dealing with aneurysms at the *base* hospitals are: (1) The operations are all performed upon young, healthy individuals, with normal, elastic arteries, who have recovered from the immediate effects of shock, surgical anemia, and exhaustion; (2) the operations are performed when time has been given to restore the efficiency of the cardiovascular mechanism, which is necessary for the establishment of the collateral circulation; (3) the survival of the pe-

ripheral parts, dependent upon the wounded artery, long after the primary injury, proves that the collateral circulation has been established, sufficiently at least, to insure their vitality; (4) the dangers of infection have been eliminated by the time the operation is performed; (5) the field of the operation is limited to the wound area, and only a limited segment of the injured vessel is excluded from the circulation.

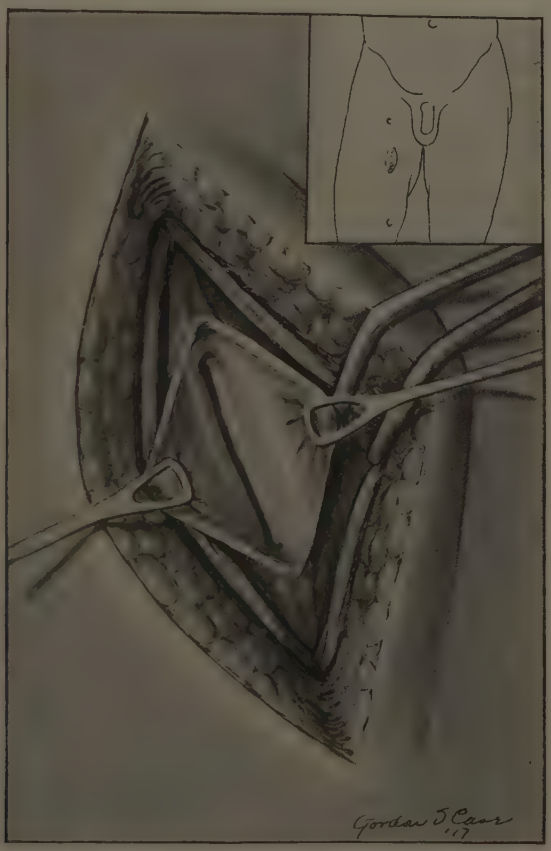


FIG. 337.—OBLITERATIVE ENDO-ANEURYSMORRHAPHY (MATAS). *Traumatic Aneurysm* (GUNSHOT) OF FEMORAL ARTERY BELOW ORIGIN OF THE PROFUNDA.

Appearance of interior of sac showing a gutter groove leading from inlet to outlet. First stage of the operation of endo-aneurysmorrhaphy (Matas). In this case the *reconstructive* operation could have been done, but it was deemed unnecessary, as previous tests showed that the collateral circulation had been fully established and that the *obliterative suture* could be applied with safety to the limb.

Outline diagram shows the position of the aneurysm and scars at entrance and exit of the bullet. (Case of L. N., twenty-five years. Operated by Dr. Matas, September 28, 1917. Perfect recovery. This and following drawings copied from sketches made in the course of the operation.)

If in the end, then, the collateral circulation is responsible for the safety of the limb in the majority of the cases, it is logical to conclude that if this is true, that *that* operation is the safest and the best which will accomplish its purpose, *i. e.*, the cure of the aneurysm with a minimum of trauma, with the least sacrifice of the injured vessel, and the least interference with the perivascular tissues. It is

also evident that, *ceteris paribus*, if the continuity of the injured vessel can be restored, and the blood-stream made to return to its normal channels, an additional safeguard and advantage will be gained which can only redound to the benefit of the dependent parts.

It is very questionable, however, whether the best results are obtained when, in the endeavor to restore the continuity of the main artery, an additional trauma is inflicted without certainty that it will

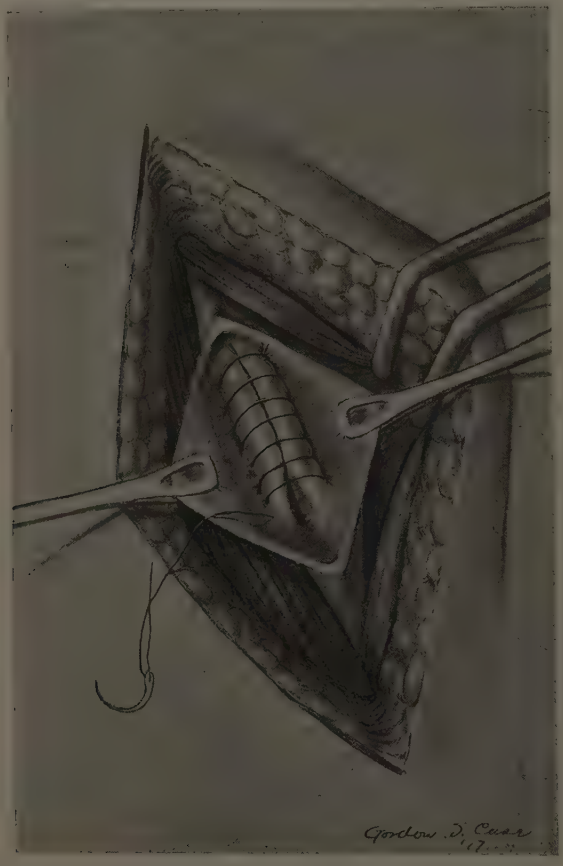


FIG. 338.—CASE OF L. N. CONTINUED (MATAS COLLECTION). TRAUMATIC ANEURYSM (GUNSHOT) OF FEMORAL ARTERY BELOW ORIGIN OF PROFUNDA. *Obliterative Endo-aneurysmorrhaphy.*
Shows a continued intrasaccular silk suture, obliterating the orifices of communication with the main artery, including the groove at the bottom leading from the inlet to the outlet of the sac.

attain its conservative purpose, and perhaps jeopardize the safety of the peripheral parts, which has already been assured by the collaterals.

The Intrasaccular Suture; Endo-aneurysmorrhaphy by the Matas Methods.—A long experience in the treatment of pathologic and traumatic aneurysms, as they occur in civilian life, in which the methods of intrasaccular suture have been exclusively applied to fully developed aneurysms, has convinced me that the impressions and conclusions arrived at by the survey of the military practice of the war have

in no way detracted in principle from the advantages of the intrasaccular suture as advocated by myself. A large and steadily increasing experience has taught me that in dealing with well-developed aneurysms the need of restorative or reconstructive operations is steadily diminishing. This is particularly true, since I have made it an invariable practice, whenever possible, to study the behavior of the peripheral circulation *as a preliminary* to the operation. Barring the cases in

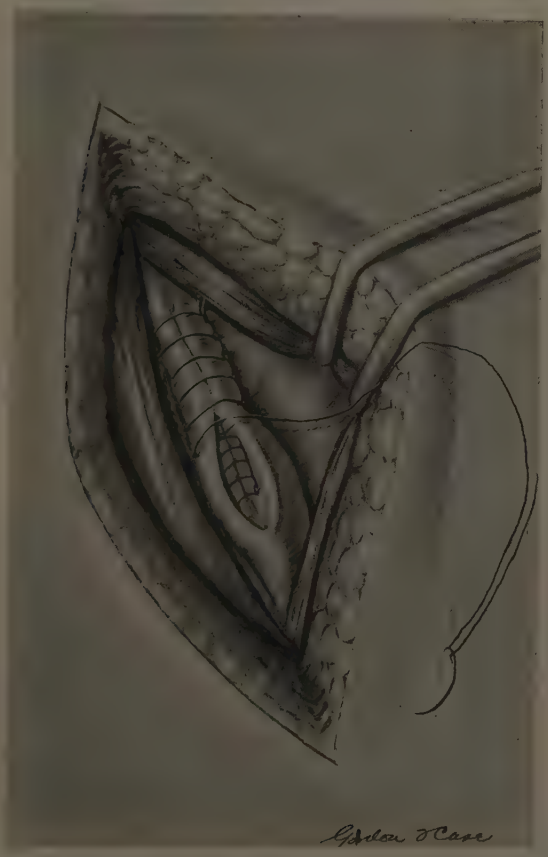


FIG. 339.—CASE OF L. N. CONTINUED (MATAS COLLECTION). TRAUMATIC ANEURYSM (GUNSHOT) OF FEMORAL ARTERY (MIDDLE THIRD). *Obliterative Endo-aneurysmorrhaphy.*
Shows the obliteration of the sac by a continued chromic gut suture which overlapped the sac walls.

which ruptured sacs, suppuration, or urgent pressure signs compel immediate action, I have been guided by the preliminary tests in selecting the most opportune moment for intervention, delaying the operation whenever the peripheral reaction indicated a feeble supplementary circulation. Contrary to the opinions of some surgeons who express doubts in the practical value of the methods of developing the collaterals, and in harmony with those who are convinced that by appropriate general treatment, which will increase the efficiency of the

cardiovascular mechanism and by local vascular exercises, I believe that the collaterals can be developed to a much greater efficiency whenever time is given for their training. For this reason the intrasaccular suture of the simple, obliterative type (Vol. V, p. 270) has been applicable to the majority of the cases that have come under my observation, and has yielded the most satisfactory results. This does not imply by any means that I have grown less confident in the efficacy of the restorative or reconstructive endo-aneurysmorrhaphies when properly applied. This only means that the call for the reconstructive type of operation in fully formed, mature sacs is much less frequent than I formerly believed it to be. When the sac communicates with the main artery by a single orifice, the simple restorative aneurysmorrhaphy is always performed if the conditions found in the sac are favorable to the suture of the orifice without occluding the lumen of the vessel. In my own experience this restoration is possible and has been applied as shown in the appended table in 33 per cent. of the cases. Since the restoration of the lumen by the intrasaccular route adds in no way to the difficulties of the technic, or complicates it by any additional trauma, it would be absurd to ignore such an excellent opportunity to do good without evil.

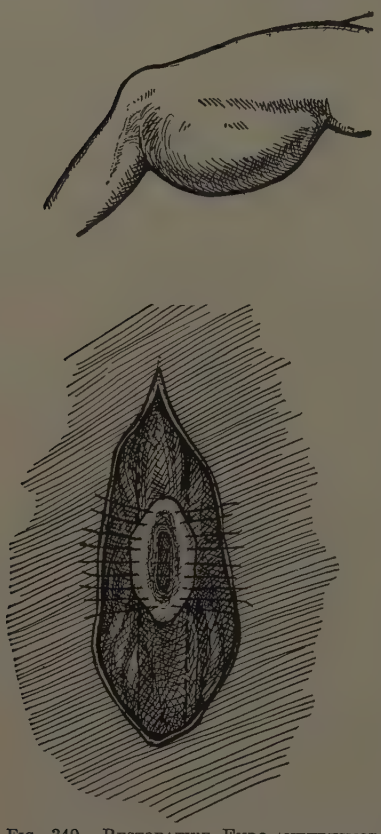
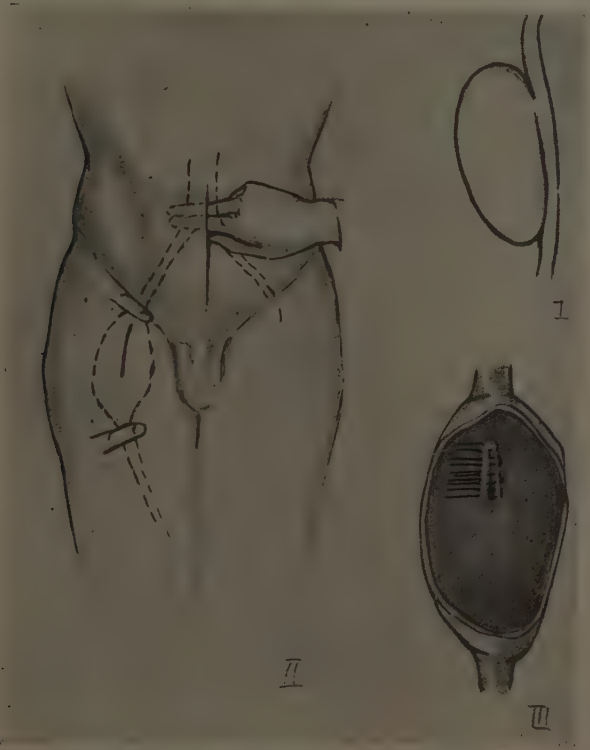


FIG. 340.—RESTORATIVE ENDO-ANEURYSMORRHAPHY (MATAS) AS APPLIED TO AN ENORMOUS HEMATOMA OF THE THIGH CAUSED BY RUPTURE OF A FEMOROPOPLITEAL ANEURYSM WITH A PARTIALLY FORMED SAC.

After the evacuation of the clot only a marginal cuff of sac was left attached to the main orifice of communication. This was closed by silk sutures without encroaching upon the lumen of the artery and thus allowing the bloodstream to continue without interruption. The first line of endothelial sutures was reinforced by an additional overlapping suture of the edges of the cuff. (From sketches obtained by courtesy of the operator, Dr. W. P. Carr, Washington, D. C., April 10, 1908. Perfect recovery.)

It has been claimed by some recent foreign writers that, while the "Matas operation" is a "good" operation, the opportunities for its application are too restricted to make it generally applicable. It is evident that such a view of the intrasaccular suture must be based upon an entire misconception of the procedure. Some seem to understand it only in its restorative or reconstructive phases, and know nothing of its obliterative type, which is also thoroughly conservative, as compared with the ligature and extirpation, and is applicable to practically all aneurysmal sacs. Others understand it to consist merely in a

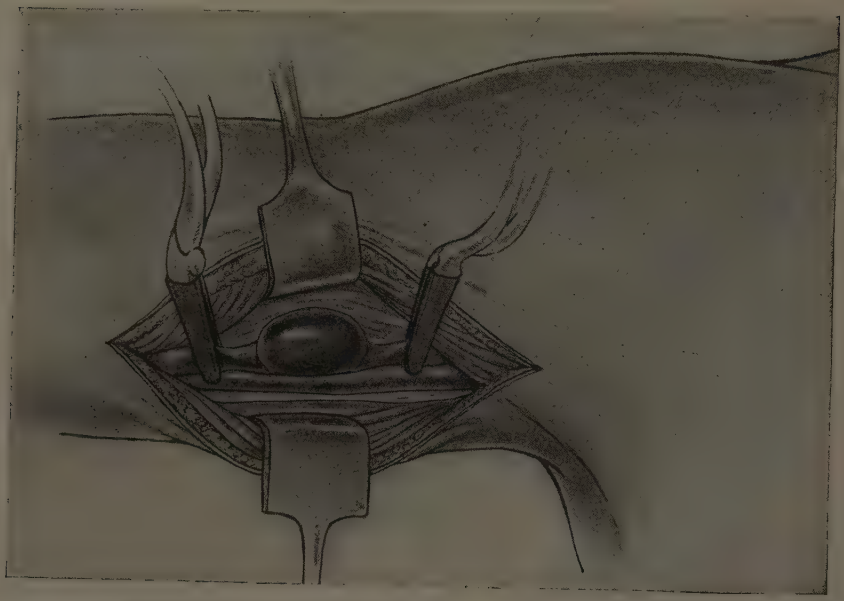
plication of the sac, whereas plication is only a supplementary step which follows after the suture of the individual orifices that open into the sac, and is only applicable when a relaxed, pliable sac permits it and allows it to collapse after the evacuation of its contents. Again, some, and especially the French surgeons, have objected to all intrasaccular operations under the impression that the sac remaining in the tissues act as a cicatricial plug or foreign body which interferes with the function of nerves, joints, etc. In my report (Trans. XVII Internat. Congress, London, 1913) will be found, under the heading "End-results," an ac-

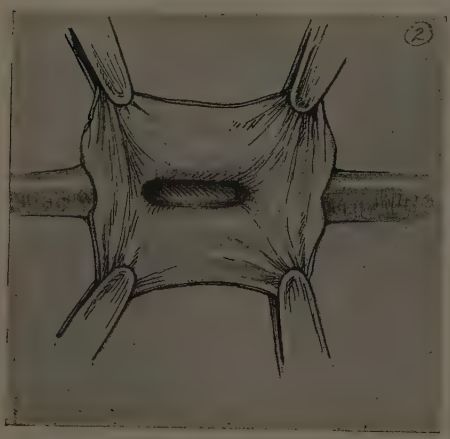


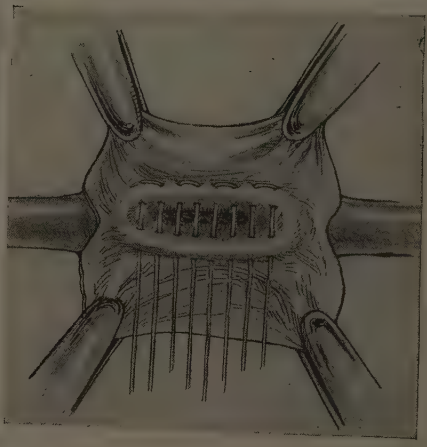
FIGS. 341, 342.—CASE OF SACCIFORM ANEURYSM OF THE UPPER FEMORAL. SUCCESSFULLY OPERATED BY DR. GEO. W. CRILE, OF CLEVELAND, OHIO, 1915.

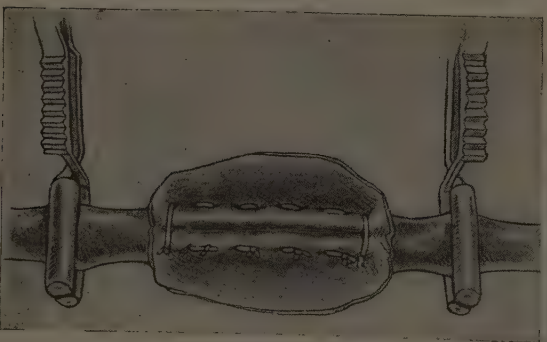
Restorative endo-aneurysmorrhaphy (Matas), followed by complete restoration of the circulation and cure of the aneurysm. *I* shows relation of sac to main artery. *II*, Position of sac in relation to the thigh and groin, also method securing provisional hemostasis by compressing the aorta and the poles of the sac. *III*, Interrupted mattress sutures closing the single orifice in the sac, leading to the main artery. (Reproduced by courtesy of Dr. Crile, from his diagrams and description.)

count of 3 cases (popliteal, femoral, and iliofemoral) in which respectively three large aneurysmal sacs were obliterated by intrasaccular suture. The patients had succumbed to other diseases from two months to three years after the operation had been performed. The specimens of the affected limbs, carefully injected and dissected by Prof. Souchon, showed that even at the end of two months the sacs had disappeared, and, in fact, in the two older cases the relics could scarcely be identified as parts of the sac. This fear of the sac remaining as such,









FIGS. 343-347.

permanently in the tissues, is purely an assumption which has no basis in actual experience. The sac, after it has been thoroughly cleared of clot, undergoes atrophic changes almost from the moment it is excluded from the circulation. It shares the fate of all supernumerary or functionless organs and structures, and disappears precisely as the *ductus arteriosus*, the umbilical arteries, etc., disappear after their fetal function has ended. It is only in old and extremely rare calcified and ossified sacs, which have been reported as curiosities, that the sac will resist the atrophic process. In such cases extirpation is, of course, the only remedy.

We can now safely assert that the cure of arterial aneurysms and the majority of the arteriovenous aneurysms is reduced by the intrasaccular suture (when at all applicable in accessible regions) to the very simplest terms. The only outfit necessary is that which is required to close an intestinal perforation, and the technic itself is precisely that which any surgeon would apply to close an intestinal perforation. Plain, curved intestinal needles, threaded with paraffined silk, are all that is especially required in addition to the general operative outfit, provided perfect prophylactic hemostasis is secured. This hemostasis is an imperative necessity, and too much care cannot be observed to secure this prime and essential condition. If there is an excess of sac which has been detached by previous dissection it can be cut out, care being taken to respect that portion which is close to the vessel. A second protective row of continued sutures is applied over the first hemostatic sutures which close the individual orifices, utilizing the relaxed folds of the sac when these are accessible, as is the case in the majority of the peripheral aneurysms. After this the sac is obliterated by the infolding or plication of its walls; but when these are adherent, rigid, or unyielding, the sac is not disturbed, and the walls are allowed to come in contact and are held in apposition by a few interrupted transfixion sutures. In certain rare cases in the neighborhood of joints, osseous surfaces (*e. g.*, popliteal), the utilization of the sac walls for plication may be impossible even for the second row of protective sutures. In such cases reliance can be safely placed upon the primary hemostatic sutures, carried right through the walls of the sac and including the margins of the orifice, if the sac walls are simply allowed to fall into place as a protective cover. The essential is to obliterate all dead spaces, utilizing buried catgut sutures wherever these may be necessary. If the sac is small, or has been cut off, leaving only a collar of sac around the sutured orifices of the vessel, the adjoining muscles can be brought in contact with the sac to fill the space left after the evacuation of its contents. In all cases, after all the orifices have been closed, the operator must satisfy himself that hemostasis is complete. The constrictor at this stage is relaxed, and the orifices of

FIGS. 343–347.—BRACHIAL ANEURYSM IN A MAN AGED FORTY-THREE YEARS.

Reconstructive endo-aneurysmorrhaphy (Matas) as sucessfully performed by the late Dr. John B. Murphy, Chicago, on September 17, 1914. The last figure shows the final disposition of the sac by overlapping the flaps over the first line of suture. (Drawn and modified from sketches published in Dr. Murphy's "Surgical Clinics," Vol. I, February, 1915.)

any bleeding collaterals which open into the sac and may have escaped detection are sutured. The sac cavity is washed off with ether, and wiped clear of all adherent laminated clot, which might remain and become organized into a false membrane, and also might conceal some collateral orifices that might lead to secondary hemorrhage. When the

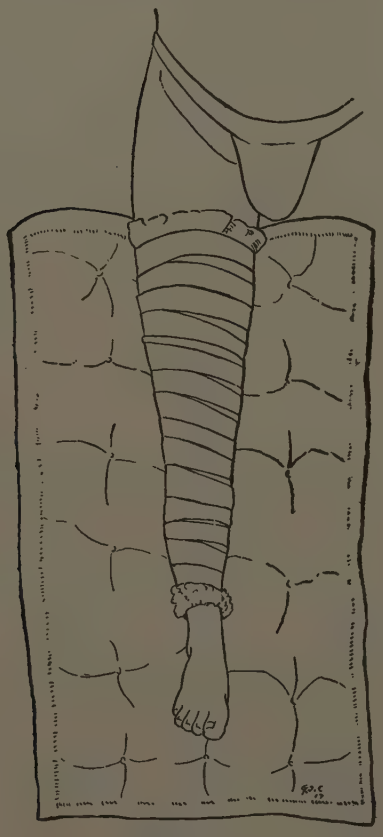


FIG. 348.—THE MATAS FELT MATTRESS PAD FOR DRESSING AND IMMOBILIZING THE LOWER EXTREMITY AFTER ANEURYSM OPERATIONS.

The regular sterile dressing to the wound is followed by a copious layer of cotton over which a comfortable gauze bandage is applied; over this the pad is adjusted, which prevents flexion of the knee and protects against pressure sores, keeps the limb warm, and permits frequent inspection of the foot and digits.

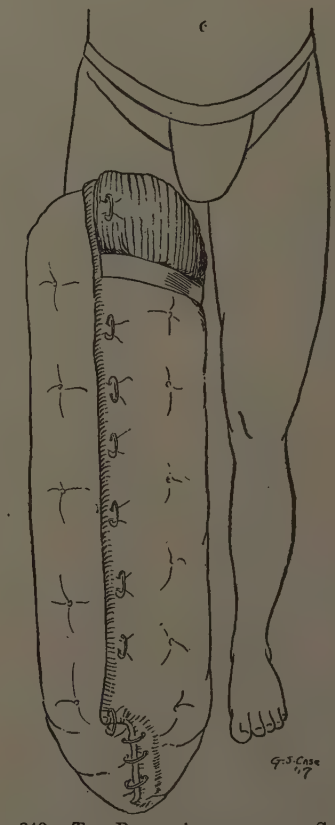


FIG. 349.—THE PAD IS ADJUSTED WITH SAFETY-PINS AND THE DRESSING IS PROTECTED FROM SOILING BY AN OILED SILK OR RUBBER SHEET AT THE GROIN.

cavity is wiped dry and the individual orifices closed, the obliteration of the sac, as previously indicated, is in order. A cigarette or silkworm (filiform) drain should be left for the first forty-eight hours in the wound if the aneurysm operated on is at all large, or the operation prolonged. The deeper muscular planes are approximated by buried catgut sutures, and the external wound with alternating deep and superficial inter-

rupted silkworm sutures. The wound is dressed with several layers of plain sterile gauze, held in place by adhesive strips. The limb is enveloped in a large, copious dressing of absorbent cotton in the immediate vicinity of the wound, and with non-absorbent cotton sheeting or batting from the tip of the extremity to the trunk. This cotton dressing should be thickest in the most distal parts, especially where the skin is subject to pressure (ankle, heel, elbow, wrist, etc.). No splints of any sort are used to immobilize the limbs; nothing, in fact, that will exercise injurious pressure and favor bed-sores, or circular bandages that will in any way compress the limb. In the lower extremity, while the limb is kept well wrapped for warmth and for protection from the effects of localized pressure, it is of the greatest importance that the movements of the limb or of the patient should not be unnecessarily restricted. The immobilization of the patient and limb in a fixed position is injurious by favoring stagnation and pressure necrosis over bony prominences. What is indicated, especially in the lower extremity (popliteal and femoral aneurysms), is that while flexion at the knee and hip is restricted, the patient should be allowed to roll the limb from side to side, and turn around, so that it may lie in any position that will be comfortable.

These indications have been met most satisfactorily in my own practice by the use of a flat mattress pad made of several sheets of heavy felt (mattress felt) 3 or 4 inches thick, and covered with ticking. This is again covered with a sheet or special pillow case, and the whole is wrapped around the limb from foot to groin, and beyond the foot for about 6 inches, so as absolutely to cover the whole extremity, especially the toes. This mattress wrap is now snugly fitted over the limb and held taut and firmly in place with strong safety-pins. When the dressing is completed the limb is firmly embaled in the dressing which not only thoroughly protects it against cold and pressure, but is firm enough to prevent flexion of the knee or hip. With the assistance of the nurse the limb can now be moved and rolled in bed (on a horizontal level), to suit the patient without fear of injury. This dressing cover (Figs. 348, 349) has proved a most valuable adjunct in the treatment of all our aneurysm cases, and of all conditions in which the peripheral circulation was impaired or in doubt.

STATISTICAL DATA: ENDO-ANEURYSMORRHAPHY OR THE INTRASACCULAR SUTURES

I have published at different times detailed statistical statements showing the status of the intrasaccular suture or *endo-aneurysmorrhaphy*. At the Seventeenth International Congress, London, August, 1913, I reported 225 cases. In the Mütter Lecture (Philadelphia, 1915) the list had increased to 289 aneurysms operated upon up to January 1, 1916. That statement is now briefly summarized in the following table, which represents the collective records of 176 operators, of whom 139 are American and 36 foreign. Of these aneurysms, approximately 35 per cent. were traumatic, and the rest pathologic.

TOTAL NUMBER OF CASES OF ENDO-ANEURYSMORRHAPHY REPORTED UP TO DECEMBER 31, 1915, BY DR. MATAS IN THE MÜTTER LECTURE, PHILADELPHIA, INCLUDING THE 225 PREVIOUSLY REPORTED AT THE INTERNATIONAL MEDICAL CONGRESS OF LONDON IN AUGUST, 1913.

Total cases up to December 31, 1915	289	
By eliminating 6 cases—4 fatal and inoperable aortic aneurysms and 2 accidental deaths	283	
Total deaths in 283 cases	13	(4.5 per cent.)
Total recoveries in 283 cases	270	(95.4 ")
Total gangrenes	12	(4.2 ")
Total secondary hemorrhages	6	(2.1 ")

Of 289 operations there were of the

Type	Cases	Per cent.	Deaths	Per cent.	Gangrenes	Per cent.
1. Obliterative	193	66.8	10	5.3	9.193	4.6
2. Restorative	65	22.5	2	3.0	1.65	1.5
3. Reconstructive	31	10.7	1	3.2	2.31	6.4

These operations cover all the large surgical arteries, including the abdominal aorta. Fully 86.1 per cent. involved the arteries of the lower extremity, including the external iliac. The popliteal aneurysms, 154 cases, represent 53.2 per cent.; the femoral, 61 cases, 21.1 per cent. of the whole. If the popliteal group is selected, as one of the best and most certain tests for all aneurysmal operations, we find that it has been performed in all the three types of endo-aneurysmorrhaphy 154 times. Of these, 103 obliterative operations were followed by 6 gangrenes, or 5.2 per cent.; 2 secondary hemorrhages, 1.3 per cent.; 3 relapses in the reconstructive group, 1.3 per cent., one of these cured by a secondary, obliterative suture. In the 154 popliteal operations there was only 1 death, 0.6 per cent. mortality, and 8 gangrenes, or 5.2 per cent. The total failures from all causes, including gangrenes, was 10, or 6.4 per cent. Five of the gangrenes occurred after the obliterative operation, one in the restorative group and two in the reconstructive. The total recoveries as to life were 143, or 99.3 per cent., and the total operative successes as to cure of the aneurysm with good functional results as to life and limb are 93.8 per cent.

By combining all the operations performed on the aneurysms of the lower extremity, from the external iliac to the tibials, the results obtained up to January 1, 1916 were 246 cases, with 230 cures and 16 failures, or 6.5 per cent. from all causes. From January 1, 1916 to September, 1919 I have records of 28 additional cases, exclusive of a considerable number of operations performed during the war by foreign surgeons, which have not been tabulated. Of these 28 endo-aneurysmorrhaphies, 17 were obliterative, 7 restorative, and 4 reconstructive. In these groups are included 7 aneurysms of the neck and upper extremities, 5 femorals, 16 popliteal, with 1 death, which happened in an exsanguinated subject after rupture of the aneurysm, operated on *in extremis:* no gangrenes; one secondary hemorrhage following a catgut suture, cured by an obliterative operation with silk. These additional cases increase our total collective list to 317 endo-aneurysmor-

rhaphies up to September, 1919,* of which 81, including 46 personal operations by myself, were performed in New Orleans and in the state of Louisiana. These do not include 19 carotid, subclavian, innominate, iliac, and femoral aneurysms, and cervical tumors requiring the extirpation of the common carotid, which were treated by myself on the Halsted principle, either with the adjustable Matas-Allen aluminum band, applied proximally in the continuity of the vessel on the Hunterian or Anel plan, or by combining the band with the direct suture of the arteriovenous communication by the transvenous route. In all of these cases operative cures were obtained, with the exception of 3 deaths from intercurrent or accidental complications (coronary heart disease, mesenteric thrombosis, and erosion hemorrhage). These 19 cases do not include 16 additional applications of the band, distally, to the common carotid and subclavian, either simultaneously or consecutively, for aortic and innominate aneurysms, in which decided relief was obtained in approximately 30 per cent.

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THE TREATMENT OF ARTERIOVENOUS ANEURYSMS AS INFLUENCED BY THE EXPERIENCE OF THE LATE WAR

Much of what has already been stated in regard to the treatment of arterial aneurysms applies equally well to arteriovenous lesions. As in the case of arterial aneurysms, we find that while all the belligerents were agreed in principle—that the "ideal treatment for arteriovenous aneurysms is that which suppresses the arteriovenous communication and at the same time conserves the physiologic integrity of the vessels involved, or, at least, the most important of the two, namely, the artery"—they differ very notably in the actual application of the principle.

Three procedures permit the conservation of the artery and a restoration of its functional integrity: The ligature of the communicating canal, the separate suture of the arterial and the venous orifices of communication after the detachment of the vessels, and the method of endo-aneurysmorrhaphy devised by Matas and adapted to arteriovenous lesions by Bickham ("Matas-Bickham" operation).

The Germans, profiting by their experience in the Balkans, and

* Up to December 1, 1919, 11 additional cases of endo-aneurysmorrhaphy have been reported to me, all by the operators. These operations involved, in the majority, the vessels of the lower extremity; all were followed by complete recovery and excellent functional result.

Note by the Editor: These statistics show an extraordinary success as to life and limb. They confirm what I have often said that Dr. Matas has accomplished more for the successful treatment of aneurysms than any other surgeon since John Hunter.—W. W. Keen.

advocating early operation in the hematoma stage (within the first three weeks), found the largest opportunities to detach the anastomosis at an early stage and to close the wounds in the vessels by either lateral or circular angiorrhaphy. The French preferred the quadruple ligature with or without extirpation of the anastomosing vessels, and this practice, with some minor modifications, was also adopted by the British surgeons. Toward the end of the war the British and French reports show a more frequent application of the suture, but still these cases were in the decided minority. Thus, according to Grégoire, though 91 cases of arteriovenous aneurysms had been reported to the Societé de Chirurgie during the period of the war, in only 9 instances had the ideal restoration of the vascular function been attempted or realized. Since that time other cases have been added. The excellent papers of Cunéo, Forgue, René Le-Fort, Lecène, Raymond Grégoire, Chutro, Sencert, Pauchet, Mauclaire, Piollet, and others indicate that the treatment of arteriovenous aneurysms by the conservative methods of suture is rapidly gaining ground in France. Even more emphatic signs that conservative methods are also gaining in favor in Britain are evident if we may judge by the writings of so eminent a representative of British opinion as Makins and several of his contemporaries.

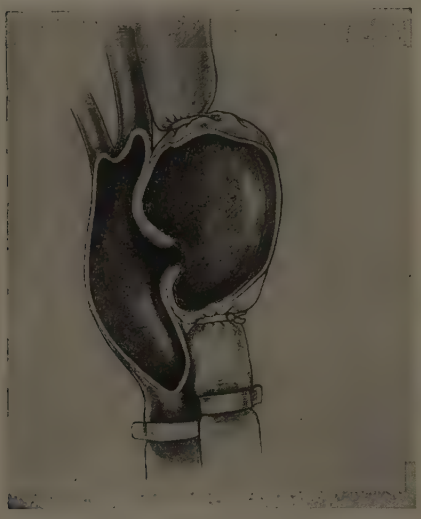

FIG. 350.—ARTERIOVENOUS ANEURYSM (ANEURYSMAL VARIX), FIFTEEN YEARS' STANDING, OF THE JUGULOCAROTID VESSELS.

Case of John G., operated on by Dr. Matas, Charity Hospital N. O., La., May 4, 1912. Shows the relations of the vessels and site of the fistula, also aluminum bands previously applied to the common carotid and internal jugular. (Reproduced from the original drawings in the Matas collection. "Osler Memorial Volume" No. II, by courtesy of the editors.)

Makins gives first place to the quadruple ligature with or without extirpation, according to the difficulties that may attend the removal of the sac, but prefers extirpation whenever this is possible. On the other hand, "if a direct opening exists between the artery and vein, the latter should be opened up freely; the communication is thus exposed and may be stitched up without further preparation. If the sac is situated between the vessels, it should be opened first; then the communication can be stitched from this aspect. If the aneurysm be on the free aspect of the artery, the sac is removed and the opening in the vessel is sewed up" (Gunshot Wounds of the Blood-vessels, p. 85). In dealing with aneurysmal varices he says, "The vessels may then be ligated above and below the level of the communication, and the varix excised. A *far preferable* method is to close the communicating opening by suture. In pure aneurysmal varices the almost invariable route to the anasto-

motic opening should be through the vein; if this procedure be adopted, the closure of the opening in the artery is easy, and that of the incision in the vein simple in the extreme."

These statements, together with the interesting cases of endo-aneurysmorrhaphy applied to arteriovenous aneurysms, recently reported by Jeafferson and Pearson, and by Makins himself, show that while the methods of ligature and extirpation are still dominant in the treatment of the so-called varicose type, the conservative methods of

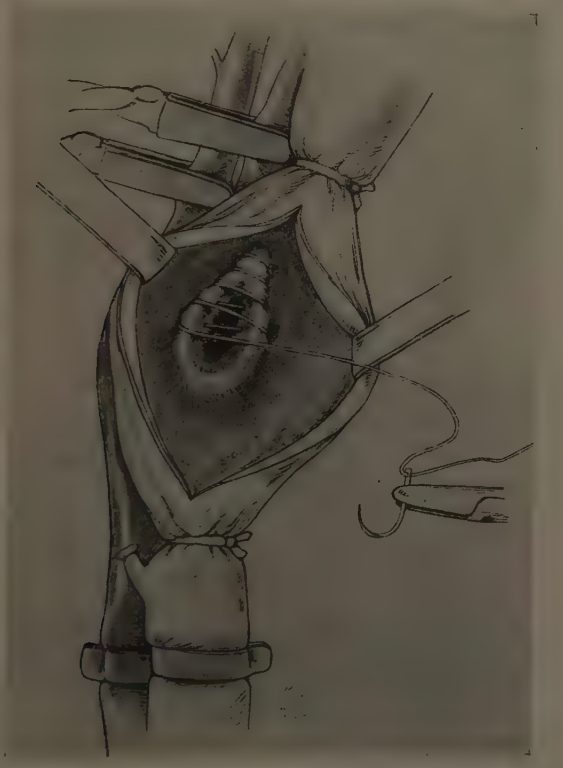

FIG. 351.—CASE OF JOHN G. (CONTINUED). ARTERIOVENOUS FISTULA EXPOSED BY OPENING THE INTERNAL JUGULAR [TRANSVENOUS ROUTE, "MATAS-BICKHAM METHOD"]. CLOSURE OF THE FISTULA WITH CONTINUED SILK SUTURE.

Method of controlling the circulation. The bands remained permanently. The external and internal carotids controlled provisionally with clamps. (From the "Osler Memorial Volume" No. II, by courtesy of the editors.)

endo-aneurysmorrhaphy as applied to aneurysmal varices by the transvenous route (which Bickham and Matas have advocated since 1904, and have been successfully practised by American surgeons long before the war) are finding more frequent application in England, as well as on the continent. The conservative methods of treating arteriovenous aneurysms, with or without communicating sacs, and the simple aneurysmal varices are sufficiently described and illustrated in my chapter in Vol. V (1908) of Keen's Surgery, and need not be repeated here.

The later experiences with the various "Matas-Bickham" procedures and the modifications adopted by several operators will be found in the contributions by Matas in the Osler Memorial Volumes and in the Annals of Surgery, vol. lxxi, 1920.

From all that has been said it is evident that there is no single method or technic that is applicable to all the varieties of arteriovenous aneurysms. Some few of these undergo spontaneous cure (perhaps more often than was formerly suspected), some are wonderfully well tolerated and do not call for any surgical treatment, and still a few

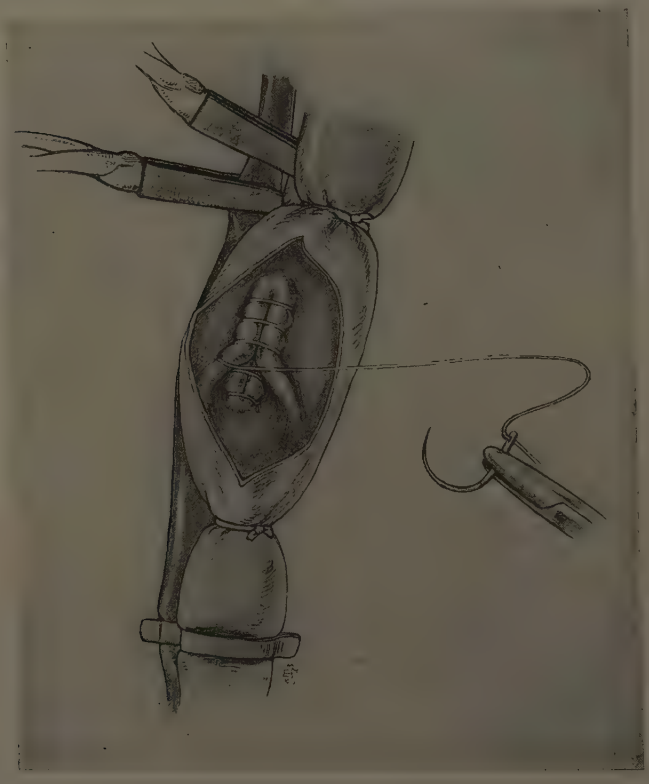

FIG. 352.—CASE OF JOHN G. (CONTINUED). OBLITERATION OF THE SAC BY INFOLDING AND SUTURING THE VENOUS WALLS IN SUPERIMPOSED LAYER AFTER CLOSURE OF THE ORIFICE. (From the "Osler Memorial Volume" No. II, by courtesy of the editors.)

others of long standing are of such a forbidding character that they scarcely justify any surgical intervention whatever. The large majority come to operation on account of disabling sequels and complications which should be anticipated by early operation. The modern operation should always aim at conservatism, and the surgeon should not delay too long whenever the systemic as well as the local effects of the lesion are becoming manifest. The operator should always approach these cases with the intention of at least saving the artery. There are, however, and always will be cases in which the conservative prin-

ciple, whether by the suture or otherwise, will have to yield, in the presence of forbidding anatomic and pathologic obstacles, to the radical methods of quadruple ligation with or without extirpation.

The time element undoubtedly plays a very prominent part in determining the probability of conservative or radical (obliterative) measures. The same rules that apply to arterial hematomas apply to the arteriovenous. In very recent injuries within a few days or three

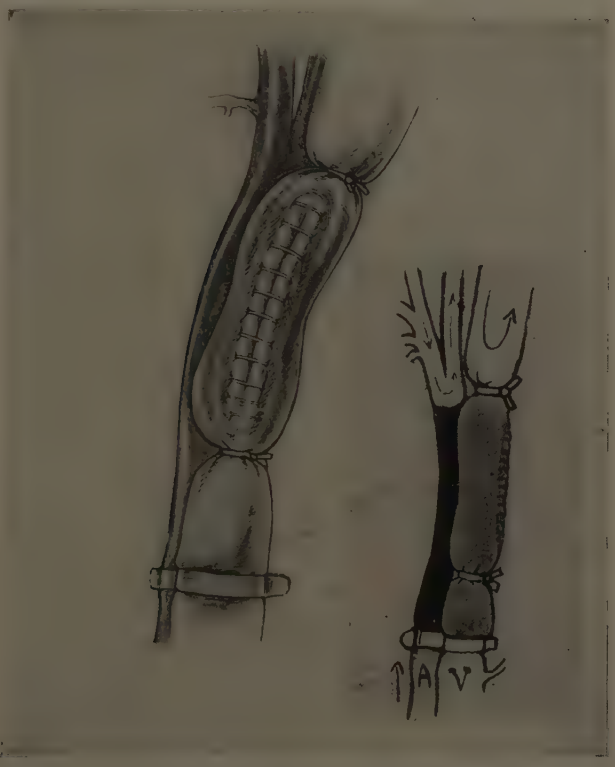

FIG. 353.—CASE OF JOHN G. (CONTINUED). SAC OBLITERATED AND CLOSED.

All circulation in the vein arrested between the permanent ligatures. Elastic padded clamps removed from the external and internal carotid arteries, thus allowing a reduced collateral circulation to continue from the external to the internal carotid, through the bifurcation in spite of the permanent occluding aluminum band on the carotid.

The smaller diagram shows areas of possible circulation in the common carotid and the jugular at the close of the operation. The black and shaded areas in the artery and the vein are stagnant areas, a small clear strip remains in the external carotid and the internal carotid showing how blood may reach the brain through the bifurcation, even after the obliteration of the common carotid. (From "Osler Memorial Volume" No. II, by courtesy of the editors.)

weeks, it is comparatively easy to isolate or mobilize the vessels and suture them either by lateral or circular arteriorrhaphy. Beyond this period it is well to wait until a permanent anastomosis has formed and the inflammatory exudation has been absorbed, thus allowing the pseudosac in varicose aneurysms to become thoroughly encysted and organized so that the suture of the orifices may be made *within* the opened sac, or, if a mere aneurysmal varix, the communicating orifice may be

more easily approached and sutured through the opened vein. I agree with Makins, Grégoire, and others, that a period of at least two or three months should elapse before the operation is attempted if the opportunity to attack the lesion within the first two weeks has passed. Furthermore, no operation should be performed without testing the efficiency of the collateral circulation and observing the effect of temporary occlusion on the peripheral circulation by mechanical compression at

FIG. 354.—ARTERIOVENOUS ANEURYSM (ANEURYSMAL VARIX), PISTOL SHOT, INVOLVING THE FEMORAL VESSELS AT THE GROIN; OF THREE YEARS' STANDING, IN WHICH THE ARTERIOVENOUS COMMUNICATION (VERY LARGE) WAS CLOSED SUCCESSFULLY BY TRANSVENOUS ENDO-ANEURYSMORRHAPHY (MATAS-BICKHAM) WITH PRESERVATION OF THE CIRCULATION IN BOTH VESSELS. (CASE OF J. H. H., NINETEEN YEARS, OPERATED ON BY DR. MATAS, JANUARY 12, 1912.)

Shows deep dissection after division of Poupart's ligament and methods of prophylactic hemostasis before attempting the detachment and separate suture of the vessels. Provisional ligature of the vessels with rubber bands and padded clamps. (From "Osler Memorial Volume" No. II, by courtesy of the editors.)

or on the cardiac side of the anastomosis by the methods I have previously described. In the carotid tracts, especially in older subjects (past forty), I prefer to apply a removable aluminum band to the artery and vein on the cardiac side, in order to watch the effect upon the cerebral circulation. The band remains undisturbed if no cerebral symptoms follow, and is removed if they appear within the first three days.

When the quadruple ligature becomes necessary, the ligature should

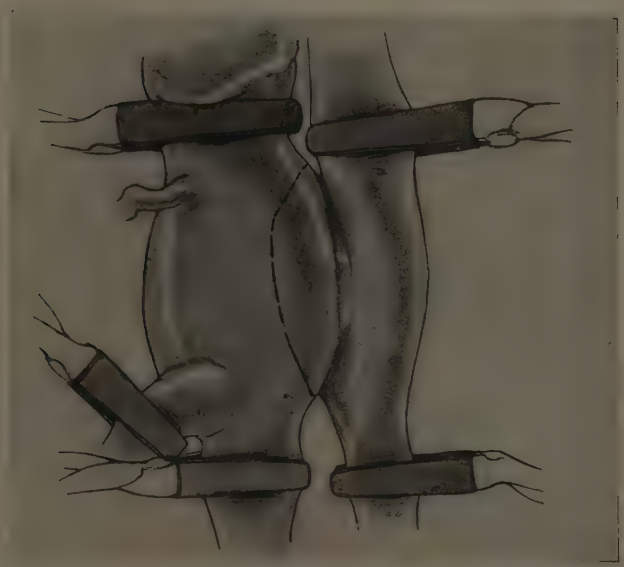

FIG. 355.—CASE OF J. H. H. (CONTINUED). DETAIL OF ANASTOMOSIS TO SHOW LINE OF INCISION ON THE VEIN IN ORDER TO EXPOSE THE INTERIOR OF THE SAC. (From "Osler Memorial Volume" No. II, by courtesy of the editors.)

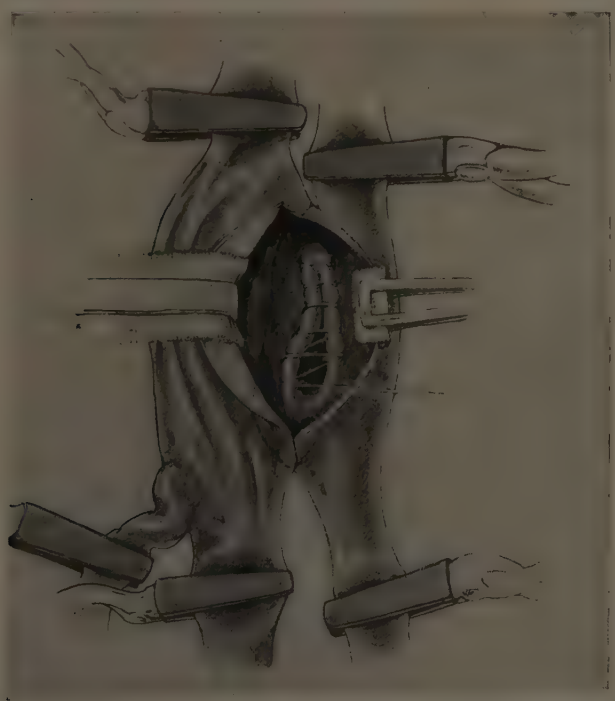

FIG. 356.—CASE OF J. H. H. (CONTINUED). INTERIOR OF THE SAC, SHOWING CLOSURE OF THE ORIFICE OF COMMUNICATION BY CONTINUED SILK SUTURE. (From "Osler Memorial Volume" No. II, by courtesy of the editors.)

be applied as *near* the seat of the anastomosis as possible, and the vessels divided right through the inosculation; or it is even better, as suggested by Cunéo, to begin by dividing the vessels right through the anastomotic orifice and then ligating the four vessels separately at each end. This procedure is usually indicated in vessels of secondary magnitude or in cases in which a varix is encased in a densely organized mass of sclerotic exudates, and the vessels cannot be identified in the mass.

In any event, if a quadruple ligature becomes necessary, it is a *serious error* to ligate the vessels *at a distance* from the lesion. This procedure is likely to be followed by a relapse if any collaterals are

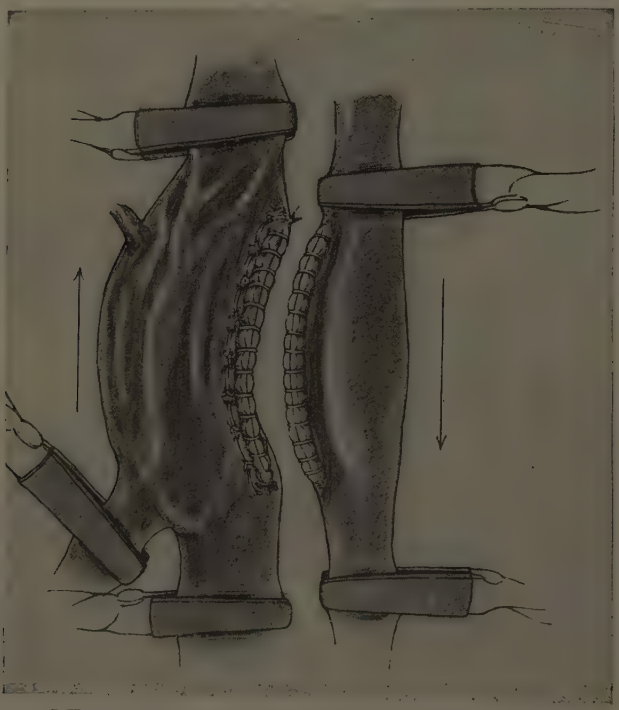

FIG. 357.—CASE OF J. H. H. (CONTINUED). THE ANASTOMOSIS CLOSED; ARTERY AND VEIN DETACHED, ISOLATED, AND SEPARATELY CLOSED BY LATERAL ARTERIORRHAPHY AND PHLEBORRHAPHY. The arterial orifice has been closed separately by intrasaccular suture on the venous side and the first line of intrasaccular sutures is reinforced at the expense of the vein. (From "Osler Memorial Volume" No. II, by courtesy of the editors.)

given off in the involved portion, and the danger of peripheral necrosis is also greater. The rule in dealing with all arterial or vascular lesions which compel ligation is to exclude from the circulation the *smallest possible segment of the vessel that is compatible with cure.* In varicose aneurysms the communicating sac, whether attached to the artery or vein, or both, should be opened freely and all visible orifices sutured separately within the sac. Even if the vessels are obliterated by this procedure, the obliteration will spare more of the artery and prove safer if it is done by the intrasaccular suture than by an extrasaccular ligature, especially after extirpation. The extirpation of the mature, well-

organized sac is unnecessary in the majority of arteriovenous aneurysms, and its removal is a superfluous traumatism which only complicates the operation. It is only when the sac is very large, rigid, or calcareous that its extirpation, in part or whole, is necessary.

PROPHYLACTIC HEMOSTASIS

This is one of the most serious problems in the operative treatment of aneurysms, and especially of the arteriovenous variety. Opinions are divided when dealing with aneurysms of the extremities. Some operators prefer to operate without the Esmarch bandage or a constrictor, and others invariably apply it—preferring a thoroughly bloodless field for their work. I have always resorted to prophylactic ischemia with the Esmarch, or by "gravity anemia," and the circular elastic constrictor. This should not be done, however, until the seat of the anastomosis has been unmistakably localized. Whenever the spot can be found, which, on pressure, is immediately followed by the total cessation of the thrill and all the aneurysmal bruits, that, of course, is the exact seat of the lesion. In deep aneurysmal communications which cannot be felt and controlled by direct pressure, it is best to rely upon the track of the missile as indicated by a line drawn from the wound of entrance to that of exit; where this line is crossed by the vessels this is likely to be the exact seat of the lesion. When the missile is retained the track of the missile can usually be determined by drawing a line from the external wound or scar to the missile, as this is shown by the *x*-ray screen or plates; the point of intersection where this line is crossed by the vessel will guide the operator to the seat of the arteriovenous fistula. In case of doubt, dissect down to the vessels and follow the thrill to the point where the index-finger will cause an immediate cessation of all signs—stilling the aneurysm.

Prophylactic Hemostasis in Operations for Aneurysms of the Neck and Trunk which Are Not Accessible to Circular Constriction.—Whatever differences may exist as to the advantages or disadvantages of a bloodless field by prophylactic constriction, there is no possible question as to the importance of controlling the vessels by preliminary provisional ligation or by clamps before any attack is made on the aneurysm. In *every case*—a rule which knows no exception—no open or radical operation on an aneurysm should be attempted without an absolute control of *both* of its poles, or, in arteriovenous aneurysms, of the two parent vessels, on each side of the lesion, and as close to it as possible. Even then the collaterals which open into the sac inside of the poles may give rise to the most formidable bleeding. This applies with more insistence to arteriovenous lesions than to the purely arterial. To obviate this, in certain cases (and I have in mind the subclavian, axillary, and carotid aneurysms) it is possible to circumscribe the sac, partially or wholly, by semicircular spring clamps, which, after controlling the poles separately, may be inserted in the peri-aneurysmal tissues in a manner that will grasp all important blood-vessels going into the sac. I have devised special clamps for this pur-

pose, but it is only in certain favorable cases that these are applicable. The chief reliance must be placed upon the prompt control of the poles with traction loops, tapes, or soft spring clamps. In dealing with the large vessels the technic suggested by Makins and Lecène for the temporary prophylactic occlusion of the vessels is likely to cause less damage to the vessel walls than other methods. This consists in passing a No. 1 or 2 soft-rubber catheter around the vessel and, after tightening the rubber, clamping with forceps (Lecène), or by encircling the artery with a tape, and then knotting it by a single surgical turn over a piece of drainage-tube of about the same caliber as the artery, placed upon its surface (Watson-Makins).

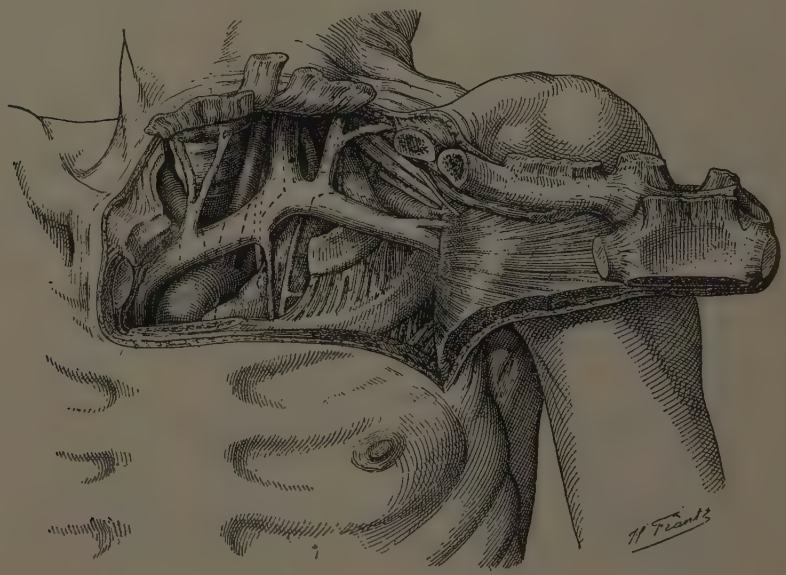

Fig. 358.—To Show Sternoclavicular Flap Retracted to Expose the Great Vessels in the Anterior Mediastinum. (Kocher-Duval Procedure.) (Sencert, Jour. de Chir., Tome xv, No. 2, Fig. 9, p. 117, 1919.)

In all aneurysms of the iliac group below the aortic bifurcation and Poupart's ligament no operation should be attempted without a preliminary control of the abdominal aorta and of the vessels on the distal side of the lesion as close to it as possible, including in this the origin of the deep epigastric and circumflex iliac, which may bleed freely through anastomosis with the internal mammary and other collaterals, even when the most complete occlusion on the cardiac side of the iliacs is maintained. In arteriovenous aneurysms it is also advantageous to exsanguinate the limb by applying an elastic bandage on the affected side and bringing the constrictor as high up and as near the aneurysm as possible in order to reduce the venous hemorrhage which is likely to occur abundantly when the sac is opened. This is particularly important in the iliofemoral tract or in the axillary region, in which a

total preliminary ischemia cannot be obtained by elastic constriction. The elastic constriction of the abdominal aorta by the method of Momburg (Vol. V, p. 189) as a substitute for direct compression of the aorta has been applied by several German surgeons during the war on aneurysms of the pelvic vessels, but the allied surgeons seem to have ignored it, or only mention it to condemn it. My personal experience with the method has satisfied me that it is not a method of general

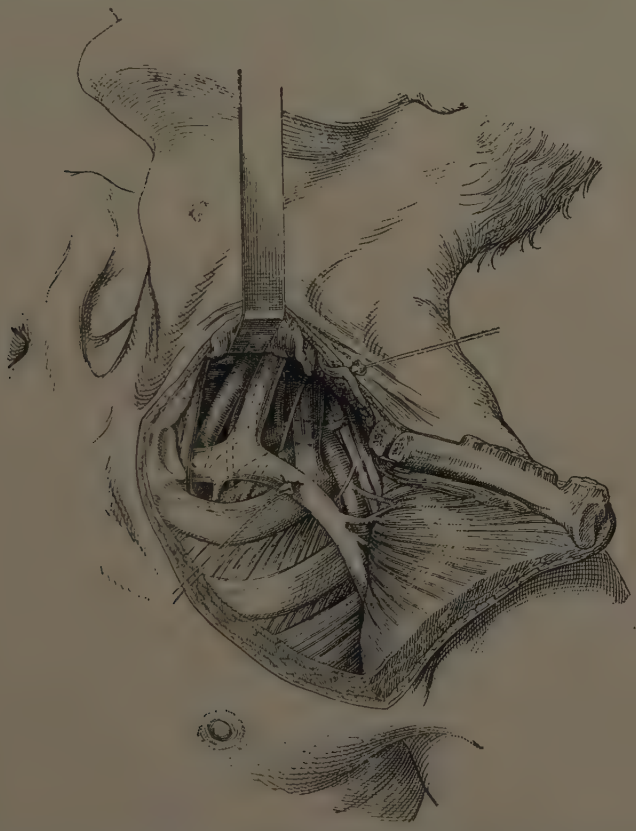

FIG. 359.—TO SHOW CLAVICULOSTERNAL OSTEOPLASTIC FLAP TO EXPOSE THE SUBCLAVIAN VESSELS, A PRELIMINARY TO THE CONTROL OF THESE VESSELS IN THE TREATMENT OF ANEURYSM. (Sencert, Jour. de Chir., Tome XV, No. 2, Fig. 6, p. 114, 1919.)

application and not altogether free from risk. But in favorable subjects with thin or relaxed abdominal walls it may render distinct service.

The most formidable cases, and those which tax the resourcefulness of the surgeon to the utmost, are the arteriovenous aneurysms of the low carotid and subclavian vessels at the root of the neck. In dealing with these the large experience of the war has taught that the only road to safety lies in large, free, open incisions which permit of free access to the aneurysm and the vessels that are attached to it on all sides. One of the effects of the late war experience has been to revolutionize the

old operative manual which drilled the students of the past in securing the blood-vessels by smallest apertures compatible with an approach to the main vessels. The day of these parsimonious buttonhole incisions is over. The need for large free routes of access to the great vessels of the neck had been long ago foreseen by Kocher. Lately his sterno-clavicular resections have been amplified and systematized by Pierre Duval, Fiolle and Delmas in a manner which has made the approach to the great vessels at their origin from the aorta a thoroughly practical performance. On the same principle of free, open exposure of the seat of lesion the old incisions and methods of approach to all the important surgical arteries have been revised. In this way the modern technic of operative surgery has been decidedly advanced. The accompanying illustrations from Sencert's admirable paper on the treatment of aneurysms at the root of the neck (Figs. 358, 359) will give a fair idea of the methods at present adopted for the approach to the great arteries.

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